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DETAILED PROGRAM 57

Monday, September 19, 1:30PM-4:00PM

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1:30PM *The Modular Embedded Multilevel Converter: A Voltage Source Converter with IGBTs and Thyristors*  
Di Zhang, Rajib Datta, Andrew Rockhill, Qin Lei and Luis Garces

1:55PM *Multi-Module-Cascade High-Voltage Composite Switch*  
Binbin Wang, Yao Lu, Xinnian Sun, Wenxi Yao and Zhengyu Lu

2:20PM *Step-Up MMC with Staircase Modulation: Analysis, Control, and Switching Strategy*  
Younes Sangsefidi and Ali Mehrizi-Sani

2:45PM *A High Step-Up Ratio Soft-Switching DC-DC Converter for Interconnection of MVDC and HVDC Grids*  
Shenghui Cui, Nils Soltau and Rik W. De Doncker

3:10PM *Fault Tolerant Cell Design for MMC-based Multiport Power Converters*  
Alberto Zapico, Mario Lopez, Alberto Rodriguez and Fernando Briz

3:35PM *HIL Platform Design and Controller Verification for MMC Based HVDC Networks*  
Luis Herrera, Xiu Yao and Jin Wang

Renewable Energy I, Chair: Wei Qiao, Liyan Qu, Room: 203C 58

1:30PM *Energy Storage Opportunities and Capabilities in a Type 3 Wind Turbine Generator*  
Eduard Muljadi, Vahan Gevorgian and Anderson Hoke

1:55PM *Assessment of System Frequency Support Effect of a PMSG-WTG Using Torque-Limit Based Inertial Control*  
Xiao Wang, Wenzhong Gao, Jianhui Wang, Ziping Wu, Weihang Yan, Vahan Gevorgian, Yingchen Zhang, Eduard Muljadi, Moses Kang, Min Hwang and Yong Cheol Kang

2:20PM *Improved Efficiency of Local EPS through Variable Switching Frequency Control of Distributed Resources*  
Jose M. Cano, Andres Suarez, Angel Navarro-Rodriguez and Pablo Garcia

2:45PM *Smart EV Charging System for Maximising Power Delivery from Renewable Sources*  
Fearghal Kineavy and Maeve Duffy

3:10PM *Instantaneous Frequency Regulation of Microgrids via Power Shedding of Smart Load and Power Limiting of Renewable Generation*  
Shuo Yan, Ming Hao Wang, Tian Bo Yang and S. Y. Ron Hui

3:35PM *Modeling and identification of harmonic instability problems in wind farms*  
Esmaeil Ebrahimzadeh, Frede Blaabjerg, Xiongfei Wang and Claus Leth Bak

Modelling, Analysis, and Control of Grid-Connected Converters, Chair: Behrooz Mirafzal, Fariba Fateh, Room: 202A 59

1:30PM *A Method for Improving Stability of LCL-Type Grid-Tied Inverters in Weak Grid with Resonant Feed forward Control*  
Yu Tang, Liuliu Huang and Guoshu Zhao

1:55PM *Passivity Enhancement in RES Based Power Plant with Paralleled Grid-Connected Inverters*  
Haofeng Bai, Xiongfei Wang and Frede Blaabjerg

2:20PM *Voltage Stability Analysis Using A Complete Model of Grid-Connected Voltage-Source Converters*  
Zhi-Xiang Zou, Andreas Martin Kettner, Giampaolo Buticchi, Marco Liserre and Mario Paolone

2:45PM *Resonant Control for Power Converters Connected to Weak and Micro Grid Systems with Variant Frequency*  
Jaime Rohten, Pedro Melin, Jose Espinoza, Daniel Sbarbaro, Jose Silva and Marcelo Perez

3:10PM *Extended-Horizon Finite-Control-Set Predictive Control of a Multilevel Inverter for Grid-Tie Photovoltaic Systems*  
Jose Silva, Jose Espinoza, Jaime Rohten, Luis Moran, Eduardo Espinosa, Carlos Baier and Javier Munoz

3:35PM *A Novel Seamless Transfer Control Strategy For Wide Range Load*  
Kiryong Kim, Dongsul Shin, Jong-Pil Lee, Tae-Jin Kim, Dong-wook Yoo and Heeje Kim

DC-DC Converters: Switched Capacitor, Chair: Alireza Khaligh, Nasser Badawi, Room: 102D 60

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Manxin Chen, Jiefeng Hu, Li Kerui and Adrian Ioinovici

1:55PM *Mixed Switched-Capacitor Based High Conversion Ratio Converter and Generalization for Renewable Energy Applications*  
Kerui Li, Manxin Chen, Jiefeng Hu and Adrian Ioinovici

2:20PM *A High Step-Up DC-DC Converter with Switched-Capacitor and ZVS Realization*  
Zhipeng Zheng and Liangzong He

2:45PM *A Flying Capacitor Multilevel Converter with Sampled Valley-Current Detection for Multi-Mode Operation and Capacitor Voltage Balancing*  
Jan Rentmeister, Christopher Schaef, Benedict Foo and Jason Stauth

3:10PM *Resonant Switched Capacitor Stacked Topology Enabling High DC-DC Voltage Conversion Ratios and Efficient Wide Range Regulation*  
Yongjun Li, Jikang Chen, Mervin John, Ricky Liou and Seth Sanders

3:35PM *Bi-Directional Bridge Modular Switched-Capacitor-Based DC-DC Converter with Phase-Shift Control*  
Ye Ding, Liangzong He and Zhao Liu

Multi-Phase Rectifiers, Chair: Luca Zarri, Mahshid Amirabadi, Room: 202E 61

1:30PM *A Review of Electronic Inductor Technique for Power Factor Correction in Three-Phase Adjustable Speed Drives*  
Pooya Davari, Yongheng Yang, Firuz Zare and Frede Blaabjerg

1:55PM *The Power-Loss Analysis and Efficiency Maximization of A Silicon-Carbide MOSFET Based Three-phase 10kW Bi-directional EV Charger Using Variable-DC-Bus Control*  
Kevin (Hua) Bai, Chenguang Jiang, Hui Teng and Bo Lei

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Firuz Zare

2:45PM *Comparison of Three-phase Active Rectifier Solutions for Avionic Applications: Impact of the Avionic Standard DO-160 F and Failure Modes*  
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3:10PM *MultiLevel Asymmetric Single-Phase Current Source Rectifiers*  
Montie Vitorino, Louelson Costa, Mauricio Correa and Cursino Jacobina

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Joao Paulo Ramos Agra Mello, Cursino Bradao Jacobina and Mauricio Beltrao Rossiter Correa

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Haoran Wang, Huai Wang, Guorong Zhu and Frede Blaabjerg

1:55PM *Power Decoupling Method for Single Phase PV System using Cuk derived micro-inverter*  
Anindita Jamatia, Vasav Gautam and Parthasarathi Sensarma

2:20PM *A Multi-port, Isolated PV Microinverter with Low Decoupling Capacitance and Integrated Battery Charger*  
Shiladri Chakraborty and Souvik Chattopadhyay

2:45PM *A Single Phase Transformerless String Inverter with Large Voltage Swing of Half Bridge Capacitors for Active Power Decoupling*  
Jinia Roy, Yinglai Xia and Raja Ayyanar

3:10PM *A-Source Impedance Network*  
Yam Siwakoti, Frede Blaabjerg, Veda Prakash Galigekere and Marian K. Kazimierczuk

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Tiantian Mu, Hongfei Wu, Lei Zhu and Wenying Jiang

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Bharath Kumar Sabbarapu, Omar Nezamuddin, Andrew McGinnis and Euzeli dos Santos

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Aluisio Alves de Melo Bento, Edison Roberto Cabral da Silva and Diego Alberto Acevedo Bueno

2:20PM *A High Step-Up Interleaved Converter with Coupled Inductor and Voltage-Lift Technique*  
Atsushi Matsuda and Hirotaka Koizumi

2:45PM *Single Resonant Cell Based Multilevel Soft-Switching DC-DC Converter for Medium Voltage Conversion*  
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Yan Zhang, Liu Jinjun, Dong Zhuo and Yanfei Liu

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Oliver Knecht, Dominik Bortis and Johann Walter Kolar

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1:55PM *Passive Auxilliary Circuit for ZVS Operation of A Wide-DC-Range Dual-Active-Bridge Bidirectional Converter for Transportation Applications*  
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2:20PM *Charge-Based ZVS Modulation of a 3-5 Level Bidirectional Dual Active Bridge DC-DC Converter*  
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Deshang Sha, Wenqi Yuan, Guo Xu, Fulin You and Jianliang Chen

3:10PM *Asymmetrical Duty-Cycle Control of Three-Phase Dual-Active Bridge Converter for Soft-Switching Range Extension*  
Jingxin Hu, Nils Soltau and Rik W. De Doncker

3:35PM *Proposal of Dual Active Bridge Converter with Auxiliary Circuit for Multiple Pulse Width Modulation*  
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Dongil Shin, Changwoo Son, Seonho Jeon, Bongjin Cho, Jinwook Han and Jingook Kim

1:55PM *Two-capacitor Transformer Winding Capacitance Models for Common-Mode EMI Noise Analysis in Isolated DC-DC Converters*  
Huan Zhang and Shuo Wang

2:20PM *Performance of Common-Mode-Voltage-Cancellation PWM Strategies with Consideration of Commutation Residues due to Double-Switching Waveforms*  
Mehdi Messaoudi, Arnaud Videt, Nadir Idir, Hocine Boulharts and Heu Vang

2:45PM *Identification of the Temporal Source of Frequency Domain Characteristics of SiC MOSFET Based Power Converter Waveforms*  
Samuel Walder, Xibo Yuan, Ian Laird and J. O. Dalton Jeremy

3:10PM *Resonance Phenomenon Influencing the Conducted-Mode Emission Test*  
Christian Wolf

3:35PM *Modeling, Analysis and Design of Differential Mode Active EMI Filters with Feedforward and Feedback Configurations for AC-DC Converters*  
Rajib Goswami, Shuo Wang and Zhang Yingjie

Modeling and Control of DC-AC converters I, Chair: Wim van der Merwe, Yi Deng, Room: 202D 66

1:30PM *Compensation for Inverter Nonlinearity Considering Voltage Drops and Switching Delays of Each Leg's Switches*  
Myeong-Chan Kang, Sang-Hoon Lee and Young-Doo Yoon

1:55PM *Small-signal Terminal-Characteristics Modeling of Three-Phase Droop-Controlled Inverters*  
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2:20PM *Enhancement of Current and Voltage Controllers Performance by Means of Lead Compensation and Anti-Windup for Islanded Microgrids*  
Federico de Bosio, Luiz Antonio de Souza Ribeiro, Francisco Freijedo, Josep Guerrero and Michele Pastorelli

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Jing Guo and Ali Emadi

3:10PM *Digital Dead-Beat and Repetitive Combined Control for Stand-Alone Four-Leg VSI*  
Alessandro Lidozzi, Luca Solero, Fabio Crescimbini, Chao Ji and Pericle Zanchetta

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Yushan Liu, Haitham Abu-Rub, Baoming Ge, Robert S. Balog and Yaosuo Xue

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Dalia Abdelhamid and Andrew Knight

1:55PM *Accurate Determination of Induction Machine Torque and Current versus Speed Characteristics*  
Emmanuel Agamloh, Andrea Cavagnino and Silvio Vaschetto

2:20PM *The Novel SLIM Method for the Determination of the Iron Core Saturation Level in Induction Motors*  
Konstantinos N. Gyftakis

2:45PM *Rotor Design to Reduce Secondary Winding Harmonic Loss for Induction Motor in Hybrid Electric Vehicle Application*  
Haodong Li and Keith Klontz

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Maher Al-Badri, Pragasen Pillay and Pierre Angers

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Jamlick Murimi Kinyua, Mohamed A. Khan and Paul Barendse

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1:55PM *Permanent Magnet Generator Turn Fault detection Using Kalman Filter Technique*  
Bo Wang, Jiabin Wang, Antonio Griffo, Vipulkumar I. Patel, Zhigang Sun, Ellis Chong and Riona Smitham

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2:45PM *Stator Insulation Quality Assurance Testing for Appliance Motors with Aluminum Windings*  
Daewoong Choi, Taejune Kang, Sang Bin Lee, Jaegyu Kim and Jihoon Kim

3:10PM *Robust detection of rotor winding asymmetries in wound rotor induction motors via integral current analysis*  
Jose Antonino-Daviu, Alfredo Quijano-Lopez, Vicente Climente-Alarcon and Carlos Garin Abellan

3:35PM *Asynchronous Motors Fault Detection Using ANN and Fuzzy Logic Methods*  
Negin Lashkari, Hamid Fekri Azgomi, Javad Poshtan and Majid Poshtan

Control of Electric Drives I, Chair: Radu Bojoi, Roberto Petrella, Room: 101CD 69

1:30PM *Minimizing Torque Ripple of Highly Saturated Salient Pole Synchronous Machines by Applying DB-DTFC*  
Michael Saur, Daniel Gaona, Jelena Zdravkovic, Bastian Lehner, Robert Lorenz and Dieter Gerling

1:55PM *Using Volt-sec. Sensing to Directly Improve Torque Accuracy and Self-Sensing at Very Low Speeds*  
Yukai Wang, Naoto Niimura, Ben Rudolph and Robert Lorenz

2:20PM *Torque Ripple Reduction for 6-stator/4-rotor-pole Variable Flux Reluctance Machines by Using Harmonic Field Current Injection*  
Beomseok Lee and Zi-Qiang Zhu

2:45PM *Novel On-Line Optimal Bandwidth Search and Auto Tuning Techniques for Servo Motor Drives*  
Chih-Jung Hsu and Yen-Shin Lai

3:10PM *Open-loop Control for Permanent Magnet Synchronous Motor Driven by Square-wave Voltage and Stabilization Control*  
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1:55PM *Grounding Concept and Common-Mode Filter Design Methodology for Transformerless MV Drives*  
Marius Mechlinski, Stefan Schroeder, Jie Shen and Rik W. De Doncker

2:20PM *Utilisation of Series Connected Transformers for Multiple Active Rectifier Units*  
Wim van der Merwe, Mathieu Giroux, Pasi Tallinen and Jonas Wahlstrom

2:45PM *Common-Mode Voltage Limits for the Transformerless Design of MV Drives to Prevent Bearing Current Issues*  
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3:10PM *A Robust Sensorless Start-up Method using Four Step Sequence for LCI system*  
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3:35PM *Virtual Voltage Source Control for 2x27 MVA Machine Test Bench*  
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3:35PM *Effect of Junction Temperature Swing Durations on a Lifetime of a Transfer Molded IGBT Module*  
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2:20PM *Design high power and high efficiency inverter operating at 13.56MHz for wireless power transfer systems*  
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Ashish Kumar, Sreyam Sinha, Alihossein Sepahvand and Khurram Afridi

3:10PM *Efficiency Optimization Method of Wireless Power Transfer System with Multiple Transmitters and Single Receiver*  
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3:35PM *Maximum Efficiency Tracking in Wireless Power Transfer for Battery Charger: Phase Shift and Frequency Control*  
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Monday, September 19, 5:30PM-7:00PM

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Weizhong Wang, Pawel Malysz, Khalid Khan, Lucia Gauchia and Ali Emadi

P102 *Performance evaluation of a hybrid thermal-photovoltaic panel*  
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P103 *On-line Wind Speed Estimation in IM Wind Generation Systems by Using Adaptive Direct and Inverse Modelling of the Wind Turbine*  
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P104 *Passivity-Based and Standard PI Controls Application To Wind Energy Conversion System*  
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P105 *Evaluation of Circulating Current Suppression Methods for Parallel Interleaved Inverters*  
Ghanshyamsinh Gohil, Lorand Bede, Remus Teodorescu, Tamas Kerekes and Frede Blaabjerg

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P302 *A Novel Method of Optimizing Efficiency in Hybrid Photovoltaic-Grid Power System*  
Liangliang Ren, Ke Jin, Ling Gu and Zhengshuo Wang

P303 *A Novel Autonomous Control Scheme for Parallel, LCL-Based UPS Systems*  
Mohammad Bani Shamseh, Atsuo Kawamura and Teruo Yoshino

P304 *Harmonic Components Based Protection Strategy for Inverter-Interfaced AC Microgrid*  
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P305 *Adaptive Virtual Inertia Control of Distributed Generator for Dynamic Frequency Support in Microgrid*  
Jianhui Meng, Yi Wang, Chao Fu and Hui Wang

P306 *Interleaved Hybrid Boost Converter with Simultaneous AC and DC Outputs for Microsource Applications*  
Amrita Sharma, Pramod Bura, R. K. Singh and Ranjit Mahanty

P307 *Robust Inverter Control Design in Islanded Microgrids Using $$-Synthesis*  
Mohsen Azizi and S. Ali Khajehoddin

P308 *Economic Analysis of a Regional Coordinated Microgrids System Considering Optimal PEVs Allocation*  
Liangle Xiao, Changsong Chen, Shanxu Duan, Hua Lin, Yawei Wang and Guozhen Hu

P309 *Design of a Cooperative Voltage Harmonic Compensation Strategy for Islanded Microgrids Combining Virtual Admittances and Repetitive Controllers*  
Cristian Blanco, Francesco Tardelli, David Diaz, Pericle Zanchetta and Fernando Briz

Poster Session: Transportation Electrification Applications, Chair: Jin Wang, Yaosuo "Sonny" Xue, Room: Exhibit Hall 76

P501 *EMI Reduction Technology in 85 kHz Band 44 kW Wireless Power Transfer System for Rapid Contactless Charging of Electric Bus*  
Tetsu Shijo, Kenichirou Ogawa, Masatoshi Suzuki, Yasuhiro Kanekiyo, Masaaki Ishida and Shuichi Obayashi

P502 *Design and Characterization of a Meander Type Dynamic Inductively Coupled Power Transfer Coil*  
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P503 *Design of S/P Compensated IPT System Considering Parameter Variations in Consideration of ZVS Achievement*  
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P504 *Coasting Control of EV Motor Considering Cross Coupling Inductance*  
Heekwang Lee, Bonkil Koo and Kwanghee Nam

P505 *Analysis and Comparison of Single Inverter Driven Series Hybrid System*  
Yongjae Lee, Kahyun Lee and Jung-Ik Ha

P506 *Control Strategy for a Modified Cascade Multilevel Inverter with Dual DC Source for Enhanced Drivetrain Operation*  
Maciej Bendyk and Patrick Chi Kwong Luk

P507 *An Investigation of DC-Link Voltage and Temperature Variations on EV Traction System Design*  
Nan Zhao, Rong Yang, Nigel Schofield and Ran Gu

P508 *Compact and High Power Inverter for the Cadillac CT6 Rear Wheel Drive PHEV*  
Mohammad Anwar, Mehrdad Teimor, Peter Savagian, Ryuichi Saito and Takeshi Matsuo

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P702 *Analysis and Design of a Switched-Capacitor Step-Up Converter for Renewable Energy Applications*  
Ricardo Mota-Varona, Ma. Guadalupe Ortiz-Lopez, Jesus Leyva-Ramos and Diego Langarica-Cordoba

P703 *Non-Isolated High-Step-Up Resonant DC/DC Converter*  
Ying Huang, Chun-Yuen Lai, Song Xiong, Siew-Chong Tan and Shu Yuen (Ron) Hui

P704 *Three Level DC-DC Converter Based on Cascaded Dual Half-Bridge Converter for Circulating Loss Reduction*  
Zhiqiang Guo and Kai Sun

P705 *Current-fed Converters with Switching cells*  
Zeeshan Aleem and Moin Hanif

P706 *Analysis of LCLC Resonant Converters for High-voltage High-frequency Applications*  
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P707 *A Novel Constant Voltage Primary-side Regulator Topology to Eliminate Auxiliary Winding*  
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P709 *Z-Source Resonant Converter with Power Factor Correction for Wireless Power Transfer Applications*  
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P710 *A High-Power-Density Single-Phase Inverter with Pulse Current Injection Power Decoupling Method*  
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P712 *A Novel Hybrid Five-Level Voltage Source Converter Based on T-Type Topology for High-Efficiency Applications*  
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P713 *Flying-Capacitor-Clamped Five-Level Inverter Based on Switched-Capacitor Topology*  
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P714 *Cascaded Three-phase Quasi-Z Source Photovoltaic Inverter*  
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P715 *Hybrid Three-Phase Four-Wire Inverters Based on Modular Multilevel Cascade Converter*  
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P716 *Hybrid Nine-Level Single-Phase Inverter Based on Modular Multilevel Cascade Converter*  
Filipe Bahia, Cursino Jacobina, Italo Silva, Nady Rocha, Bruno Luna and Phelipe Rodrigues

P717 *Multilevel Converter Based on Cascaded Three-Leg Converters With Reduced Voltage and Current*  
Edgard Fabricio, Cursino Jacobina, Nady Rocha, Lacerda Rodrigo and Correa Mauricio

P718 *Operation of modular matrix converter with hierarchical control system under cell failure condition*  
Yushi Miura, Tomoaki Yoshida, Takuya Fujikawa, Takuma Miura and Toshifumi Ise

P719 *The Delta-Connected Cascaded H-Bridge Converter Application in Distributed Energy Resources and Fault Ride Through Capability Analysis*  
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P901 *Dual Sequence Current Control Scheme Implemented in DSRF with Decoupling Terms Based on Reference Current Feed-Forward*  
Sizhan Zhou, Jinjun Liu and Zhang Yan

P902 *Injecting 3rd Harmonic into the Input Curent to Improve the Power Factor of DCM Buck PFC Converter*  
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P903 *Investigation of Reducing the Influence of Digital Control Delay to LCL-Type Grid-Connected Inverter*  
Guoshu Zhao, Junyang Ma, Liuliu Huang and Yu Tang

P904 *Repetitive Control for Grid Connected Inverters with LCL Filter under Stationary Frame*  
Yi Xiao, Gan Wei, Xueguang Zhang, Qiang Gao and Dianguo Xu

P905 *Direct Instantaneous Ripple Power Predictive Control for Active Ripple Decoupling of Single-Phase Inverter*  
Baoming Ge, Xiao Li, Haiyu Zhang, Yushan Liu, Bayhan Sertac, Robert S. Balog and Haitham Abu-Rub

P906 *Input-Output Feedback Linearization Based Control for Quasi-Z-Source Inverter in Photovoltaic Application*  
Hong Gong, Yuan Li, Yuhong Wang and Rui Zhang

P907 *A Novel Neutral Point Potential Control for the Three-Level Neutral-Point-Clamped Converter*  
Hsin-Chih Chen, Meng-Jiang Tsai, Yao-Bang Wang and Po-Tai Cheng

P908 *Phase Leading Input Current Compensation for CRM Boost PFC Converter*  
Chengdong Zhao, Junming Zhang and Xinke Wu

P909 *Paralleled Inverters with Zero Common-mode Voltage*  
Dong Jiang and Zewei Shen

P910 *A Voltage Clamp Circuit for the Real-Time Measurement of the On-State Voltage of Power Transistors*  
Lei Ren, Qian Shen and Chunying Gong

P911 *Error-Voltage Based Open-Switch Fault Diagnosis Strategy for Matrix Converters with Model Predictive Control Method*  
Hui Deng, Tao Peng, Hanbing Dan, Mei Su and Jingrong Yu

P912 *Instrumented Diode Dedicated to Semiconductor Temperature Measurement in Power Electronic Converters*  
Ibrahima Ka, Yvan Avenas, Laurent Dupont, Mickael Petit, Raha Vafaei, Benoit Thollin and Jean-Christophe Crebier

P913 *Reliability Odometer of Power Semiconductor Device Used for high performance high power amplifiers*  
Fei Xu, Juan Antonio Sabate, Xi Lu, Ruxi Wang, Louis Martin Frigo, Margaret Ann Wiza, Syedsaad Asif Ali and Melissa Jean Freeman

P914 *Energy and Computational Efficient Estimation of Battery Intrinsic Parameters*  
Chun Sing Cheng, Ricky Wing Hong Lau, Henry Shu Hung Chung and N.K. Rathi

P915 *Snubber Capacitors Optimization for Super-Junction MOSFET in the ZVS Full-Bridge Inverter*  
Yenan Chen, Guangyuan Liu, Changsheng Hu and Dehong Xu

Poster Session: Electrical Machines, Chair: Bruno Lequesne, Mohammad Islam, Room: Exhibit Hall 82

P1101 *A Computational Technique for Iron Losses in Electrical Machines*  
Omar Bottesi, Luigi Alberti, Ruth V. Sabariego and Johan Gyselinck

P1102 *Saliency Harmonic Induction Motor Speed Estimation Using Artificial Neural Networks*  
Abdulelah Alkhoraif and Donald Zinger

P1103 *Reclosing Transients in Standard and Premium Efficiency Induction Machines in the Presence of Voltage Unbalance*  
Tumelo Gabaraane, Paul Barendse and Azeem Khan

P1104 *Parameter sensitivity of large electric machines*  
Jemimah Akiror, Pragasen Pillay and Arezki Merkhouf

P1105 *Optimal Winding Arrangement of a Surface-Mounted Permanent Magnet Motor for Torque Ripple Reduction*  
Junichi Asama, Yamamoto Yo, Oiwa Takaaki and Chiba Akira

P1106 *Numerical Study of Convective Heat Transfer in the End Region of A Totally Enclosed Permanent Magnet Synchronous Machine*  
Ayoub Ben Nachouane, Abdenour Abdelli, Guy Friedrich and Stephane Vivier

P1107 *Torque Improvement of Wound Field Synchronous Motor for Electric Vehicle by PM-assist*  
Sung-Woo Hwang, Jae-Han Sim, Jung-Pyo Hong, Jiyoung Lee and Jongmoo Kim

P1108 *Torque Ripple Reduction of a Variable Flux Motor*  
Amirmasoud Takbash, Maged Ibrahim and Pragasen Pillay

P1109 *An Analytical Model for a Spoke Type Variable Flux Permanent Magnet Motor on No-load Condition*  
Amirmasoud Takbash and Pragasen Pillay

P1110 *Sensitivity of Manufacturing Tolerances on Cogging Torque in Interior Permanent Magnet Machines with Different Slot/Pole Number*  
Xiao Ge and Z. Q. Zhu

P1111 *Cogging Torque Minimization in Flux-Switching Permanent Magnet Machines by Tooth Chamfering*  
Xiaofeng Zhu, Wei Hua and Ming Cheng

P1112 *Experimental research on the oil cooling of the end winding of the motor*  
Ye Li, Tao Fan, Wei Sun, XuHui Wen and Qi Li

P1113 *A Computationally Efficient Method for Calculation of Strand Eddy Current Losses in Electric Machines*  
Alireza Fatemi, Dan Ionel, Nabeel Demerdash, David Staton, Rafal Wrobel and Chong Yew Chuan

P1114 *Core Loss Estimation in Electric Machines with Flux Controlled Core Loss Tester*  
Burak Tekgun, Yilmaz Sozer, Igor Tsukerman, Parag Upadhyay and Steven Englebertson

P1115 *Thermal Analysis of a Three-Phase 24/16 Switched Reluctance Machine Used in HEVs*  
Michael Kasprzak, James W. Jiang, Berker Bilgin and Ali Emadi

P1116 *Pre-Drive Test of an Implemented Novel Radial-Gap Helical ROTLIN Machine*  
Christophe Cyusa Simba and Yasutaka Fujimoto

P1117 *Hybrid Excitation Topologies of Synchronous Generator for Direct Drive Wind Turbine*  
Maxime Ployard, Ammar Aymen, Gillon Frederic, VIdo Lionel and Laloy Daniel

P1118 *Resonant Based Backstepping Direct Power Control Strategy for DFIG Under Both Balanced and Unbalanced Grid Conditions*  
Xiaohe Wang, Dan Sun and Ziqiang Zhu

P1119 *Design and Analysis of a New Five-Phase Brushless Hybrid-Excitation Fault-Tolerant Motor for Electric Vehicles*  
Li Zhang, Ying Fan, Ronghua Cui, ChenXue Li and Ming Cheng

P1120 *Multi-objective Design Optimisation and Pareto Front Visualisation of Radial-flux Eddy Current Coupler for Wind Generator Drive Train.*  
Abram Stephanus Erasmus and Maarten Kamper

P1121 *Reducing Estimated Parameters of a Synchronous Generator for Microgrid Applications*  
Mohammad Rasouli and Reza Sabzehgar

P1122 *Brushless Dual-Electrical-Port, Dual Mechanical Port Machines Based on the Flux Modulation Principle*  
Dawei Li, Ronghai Qu, Jian Li, Dong Jiang, Xiang Ren and Yuting Gao

Poster Session: Electric Drives, Chair: Uday Deshpande, Gianmario Pellegrino, Room: Exhibit Hall 86

P1301 *An Equivalent Dual Three-phase SVPWM Realization of the Modified 24-Sector SVPWM Strategy for Asymmetrical Dual Stator Induction Machine*  
Kun Wang, Xiaojie You, Chenchen Wang and Minglei Zhou

P1302 *A Speed estimation method for free-running induction motor with high inertia load in the low speed range*  
Toshie Kikuchi, Yasushi Matsumoto and Akira Chiba

P1303 *Design Optimization and Performance Investigation of Novel Linear Switched Flux PM Machines*  
Qinfen Lu, Yihua Yao, Jiameng Shi, Xiaoyan Huang, Youtong Fang, Yunyue Ye and Wei Xu

P1304 *A Coordinated SVPWM without sector identification for Dual inverter fed Open Winding IPMSM System*  
Min Chen and Dan Sun

P1305 *Finite-Control-Set Model Predictive Current Control for PMSM Using Grey Prediction*  
Wencong Tu, Guangzhao Luo, Rong Zhang, Zhe Chen and Ralph Kennel

Poster Session: Power Semiconductor Devices, Passive Components, Packaging, Integration, and Materials, Chair: Giovanna Oriti, Enrico Santi, Room: Exhibit Hall 86

P1501 *The Impact of Triangular Defects on Electrical Characteristics and Switching Performance of 4H-SiC PiN Diodes*  
Yeganeh Bonyadi, Peter Gammon, Roozbeh Bonyadi, Olayiwola Alatise, Ji Hu, Steven Hindmarsh and Philip Mawby

P1502 *Performance Evaluation of Series Connected 15 kV SiC IGBT Devices for MV Power Conversion Systems*  
Kasunaidu Vechalapu, Abhay Negi and Subhashish Bhattacharya

P1503 *Comparative Performance Evaluation of Series Connected 15 kV SiC IGBT Devices and 15 kV SiC MOSFET Devices for MV Power Conversion Systems*  
Kasunaidu Vechalapu, Abhay Negi and Subhashish Bhattacharya

P1504 *Equivalent Circuit Models and Model Validation of SiC MOSFET Oscillation Phenomenon*  
Tianjiao Liu, Runtao Ning, Thomas Wong and Z. John Shen

P1505 *Enabling DC Microgrids with MV DAB Converter based on 15 kV SiC IGBT and 15 kV SiC MOSFET*  
Awneesh Tripathi, Krishna Mainali, Sachin Madhusoodhanan, Kasunaidu Vechalapu, Ritwik Chattopadhyay and Subhashish Bhattacharya

Poster Session: Emerging Technologies and Applications, Chair: Xiaonan Lu, Pericle Zanchetta, Room: Exhibit Hall 87

P1701 *An LC Compensated Electric Field Repeater for Long Distance Capacitive Power Transfer*  
Hua Zhang, Fei Lu, Heath Hofmann, Weiguo Liu and Chris Mi

P1702 *A Selection Method of Mutual Inductance Identification Models Based on Sensitivity Analysis for Wireless Electric Vehicle Charging*  
Fang Liu, Zhengming Zhao, Yiming Zhang, Kainan Chen, Fanbo He and Liqiang Yuan

P1703 *Short-Circuit Protection of Power Converters Using SiC Current Limiters*  
Mahmood Alwash, Mark Sweet, Ekkanath Madathil Sankara Narayanan and Graham Bruce

P1704 *Impedance Measurement of Three-Phase Grid-Connected Systems in DQ-Domain: Applying MIMO-Identification Techniques*  
Tomi Roinila, Tuomas Messo and Aapo Aapro

P1705 *A New Design Methodology for a 1-Meter Distance, 6.78MHz Wireless Power Supply System for Telemetries*  
Lee Seung-Hwan, Lee Jun-Ho and Yi Kyong-Pyo

P1706 *Modeling and Investigation of 4-Coil Wireless Power Transfer System with Varying Spatial Scales*  
Lu Chen, Fuxin Liu, Xinbo Ruan and Xuling Chen

P1707 *Vehicular Integration of Wireless Power Transfer Systems and Hardware Interoperability Case Studies*  
Omer Onar, Steven Campbell, Larry Seiber, Cliff White and Madhu Chinthavali

Tuesday, September 20, 8:30AM-11:00AM

Photovoltaic Converters I, Chair: Francisco Canales, Liming Liu, Room: 203AB 89

8:30AM *Low Power Factor Operation of the PV Inverter with Power Decoupling Function*  
Yusuke Seta and Toshihisa Shimizu

8:55AM *Stand-Alone Photovoltaic Asymmetrical Cascade Converter*  
Alan Felinto, Italo da Silva, Cursino Jacobina, Joao Mello, Isaac Freitas and Nustenil Marinus

9:20AM *Ground Leakage Current Suppression in a 50 kW 5-level T-type Transformerless PV Inverter*  
Lu Wang, Yanjun Shi, Yuxiang Shi, Ren Xie and Hui Li

9:45AM *A High Performance T-type Single Phase Double Grounded Transformer-less Photovoltaic Inverter with Active Power Decoupling*  
Yinglai Xia, Jinia Roy and Raja Ayyanar

10:10AM *Low Leakage Current Transformerless Three-Phase Photovoltaic Inverter*  
Liwei Zhou, Feng Gao, Guang Shen, Tao Xu and Weiqi Wang

10:35AM *Operation of Dual-Input Central Capacitor Photovoltaic Inverter under Unbalanced Grid Voltage Condition*  
Mengxing Chen, Feng Gao and Chongsheng Jia

Modular Multi-Level Converters, HVDC, and DC Grids II, Chair: Rajib Datta, Ali Mehrizi-Sani, Room: 203DE 90

8:30AM *Impact on Small-Signal dynamics of Using Circulating Currents Instead of AC-Currents to Control the DC Voltage in MMC HVDC Terminals*  
Gilbert Bergna, Jon Are Suul and Salvatore D'Arco

8:55AM *Control of VSC-HVDC with Electromechanical Characteristics and Unified Primary Strategy*  
Weiyi Zhang, Kumars Rouzbehi, J. Ignacio Candela, Alvaro Luna and Pedro Rodriguez

9:20AM *A Novel Interline DC Power Flow Controller for Meshed HVDC Grids*  
Guangfu Ning, Wu Chen and Xu Zhu

9:45AM *Impedance-based and Eigenvalue based Stability Assessment Compared in VSC-HVDC System*  
Mohammad Amin, Atle Rygg and Marta Molinas

10:10AM *Performance Analysis of a Triple-Active Bridge Converter for Interconnection of Future DC-Grids*  
Markus Neubert, Anton Gorodnichev, Jan Gottschlich and Rik W. De Doncker

10:35AM *Dc Fault Protection of Multi-Terminal VSC-HVDC System with Hybrid Dc Circuit Breaker*  
Yalong Li, Jin Liu, Xiaojie Shi, Fred Wang and Leon Tolbert

Renewable Energy II, Chair: Alex.Q Huang, Xueguang Zhang, Room: 203C 91

8:30AM *Partial Power DC-DC Converter for Photovoltaic String Inverters*  
Alexander Morrison, Jaime Zapata, Samir Kouro, Marcelo Perez, Thierry Meynard and Hugues Renaudineau

8:55AM *On Reactive Power Injection Control of Distributed Grid-tied AC-stacked PV Inverter Architecture*  
Hamidreza Jafarian, Babak Parkhideh, Johan Enslin, Robert Cox and Shibashis Bhowmik

9:20AM *A Cost-Effective Power Ramp-Rate Control Strategy for Single-Phase Two-Stage Grid-Connected Photovoltaic Systems*  
Ariya Sangwongwanich, Yongheng Yang and Frede Blaabjerg

9:45AM *Delta Power Control Strategy for Multi-String Grid-Connected PV Inverters*  
Ariya Sangwongwanich, Yongheng Yang, Frede Blaabjerg and Dezso Sera

10:10AM *Battery Storage Sizing for a Grid Tied PV System Based on Operating Cost Minimization*  
Mohamed Badawy, Fatih Cingoz and Yilmaz Sozer

10:35AM *Dynamic Braking System of a Tidal Generator*  
Eduard Muljadi, Alan Wright, Vahan Gevorgian, James Donegan, Cian Marnagh and Jarlath McEntee

Utility Applications I, Chair: Hirofumi Akagi, Rajasekharareddy Chilipi, Room: 202A 92

8:30AM *Multi-frequency Power Routing for Cascaded H-Bridge Inverters in Smart Transformer Application*  
Youngjong Ko, Markus Andresen, Giampaolo Buticchi, Luca Concari and Marco Liserre

8:55AM *A High Power Medium Voltage Resonant Dual Active Bridge for DC Distribution Networks*  
Mohammed Agamy, Dong Dong, Luis J. Garces, Yingqi Zhang, Mark Dame, Ashraf Said Atalla and Yan Pan

9:20AM *Mu synthesized robust controller for multi-SST islanded smart grid*  
Tong Yao, Isaac Leonard, Raja Ayyanar and Konstantinos Tsakalis

9:45AM *Cascaded Open-End Winding Transformer based DVR*  
Gregory Carlos, Cursino Jacobina, Euzeli Dos Santos Jr. and Joao Mello

10:10AM *Modeling and Control of Gan Based Multiport Power Converter*  
Mohammed Alsolami, Xuan Zhang, Karun Potty and Jin Wang

10:35AM *Economic Feasibility Analysis and Operational Testing of a Community Energy Storage System*  
Ben Knueven, Jim Ostrowski, Ben Ollis, Philip Irminger, Michael Starke, Andrew Herron, Dan King, Bailu Xiao, Yaosuo Xue, Peter Karlson, Christine Labaza, David Maxwell, Seelan Thambiappah, Pablo Valencia and Sebastien Massin

Electric Machines for Transportation Electrification, Chair: Akira Chiba, Emmanuel Agamloh, Room: 102D 93

8:30AM *Electrical machine acoustic noise reduction based on rotor surface modifications*  
Andreas Andersson and Torbjorn Thiringer

8:55AM *Integrated Control of an IPM Motor Drive and Hybrid Energy Storage System for Electric Vehicles*  
Mohamed Badawy, Tausif Husain and Yilmaz Sozer

9:20AM *Investigation and Analysis of Temperature Effects on Interior Permanent Magnet Machines*  
Silong Li, Bulent Sarlioglu, Sinisa Jurkovic, Nitin Patel and Peter Savagian

9:45AM *A Novel Flux-Switching Permanent Magnet Motor-Compressor with Integrated Airfoil-Shaped Rotor Design*  
Yingjie Li, Dheeraj Bobba, Erik Schubert, Hao Ding, Casey Morris and Bulent Sarlioglu

10:10AM *Novel 6-Slot 4-Pole Dual-Stator Flux-Switching Permanent Magnet Machine Comparison Studies for High-Speed Applications*  
Yingjie Li, Ju Hyung Kim, Riccardo Leuzzi, Mingda Liu and Bulent Sarlioglu

10:35AM *High-Specific-Power Electric Machines for Electrified Transportation Applications - Technology Options*  
Xiaolong Zhang and Kiruba Sivasubramaniam Haran

Multilevel Converter Applications, Chair: Giri Venkataramanan, Qin Lei, Room: 202E 94

8:30AM *A Fully FPGA-Based Real-time Simulator for the Cascaded STATCOM*  
Jianxin Zhu, Guodong Teng, Yang Qin, Daorong Lu, Haibing Hu and Yan Xing

8:55AM *A Broad Range of Speed Control of a Permanent Magnet Synchronous Motor Driven by a Modular Multilevel TSBC Converter*  
Wataru Kawamura, Yuto Chiba and Hirofumi Akagi

9:20AM *Comparison of SiC and GaN Devices for Front-End Isolation of Quasi-Z-Source Cascaded Multilevel Photovoltaic Inverter*  
Yushan Liu, Baoming Ge, Haitham Abu-Rub, Haiyu Zhang and Robert S. Balog

9:45AM *Which is more suitable to a Modular Multilevel SDBC Inverter for Utility-Scale PV Applications, Phase-Shifted PWM or Level-Shifted PWM?*  
Paul Sochor and Hirofumi Akagi

10:10AM *A Symmetrical Hybrid Nine-Level Inverter for High Speed Open-Winding Motor Drive System*  
Kui Wang, Yongdong Li, Zedong Zheng, Dabo Wei and Boran Fan

10:35AM *Control of Neutral-Point Voltage in Three-Phase Four-Wire Three-Level NPC Inverter Based on the Disassembly of Zero Level*  
Chenchen Wang, Xiahe Si and Hongliang Xin

Modeling and Control of DC-DC Converters I, Chair: Johann Walter Kolar, Juan Rivas-Davila, Room: 102C 95

8:30AM *Observer-based Nonlinear Control for Frequency Modulated Dual-Active-Bridge Converter*  
Duy-Dinh Nguyen, Manh-Linh Nguyen, Tuyen Nguyen-Duc and Goro Fujita

8:55AM *Novel Control Architecture for Dual Output DC-DC Converter Driving DC-AC Inversion System*  
Zhi Geng, Dazhong Gu and Dariusz Czarkowski

9:20AM *Dynamic Bus Voltage Control for Light Load Efficiency Improvement of Two-stage Voltage Regulator*  
Chao Fei, Mohamed Ahmed, Fred Lee and Qiang Li

9:45AM *A Novel Large-Signal Stability Analysis Approach Based on Semi-Tensor Product of Matrices With Lyapunov Stability Theorem Using for DC-DC Converters*  
Hong Li, Fang Ren, Bo Zhang, Jianing Shang, Jinhu Lv and Hongsheng Qi

10:10AM *A Study on the Control Loop Design of Non-Isolated Configurations for Hybrid Storage Systems*  
Ramy Georgious, Jorge Garcia, Angel Navarro-Rodriguez and Pablo Garcia

10:35AM *Effects of Non-Ideal Compensators for the High-Bandwidth Low-Standby-Power Computer V-Core Converter Applications*  
Ching-Wei Yin, Dan Chen, Sheng-Fu Hsiao, Ching-Jan Chen and Hung-Shou Nien

Modulation Techniques I, Chair: Suman Debnath, Liliana de Lillo, Room: 102E 96

8:30AM *A Unified SVM Algorithm for Lifetime Prolongation of Thermally-Overheated Power Devices in Multi-Level Inverters*  
Mokhtar Aly, Gamal M. Dousoky, Emad M. Ahmed and Masahito Shoyama

8:55AM *Pulse-Width Modulation Strategy in Double-Delta Sourced Windings*  
Yongsoon Park and Seung-Ki Sul

9:20AM *A Quasi-Periodic Modulation Strategy to Mitigate EMI for a GaN-based Quasi-Z-Source DC-DC Converter*  
Saad Ul Hasan and Graham E. Town

9:45AM *A General Space Vector PWM Scheme for Multilevel Inverters*  
Fa Chen and Wei Qiao

10:10AM *Suppression of Common Mode Circulating Current for Modular Paralleled Three-phase Converters based on Interleaved Carrier Phase-shift PWM*  
Zhongyi Quan and Yun Wei Li

10:35AM *Modulation Strategies for Three-Phase AC-DC Matrix Converters: a Comparison*  
Michele Mengoni, Luca Zarri, Angelo Tani, Giovanni Serra, Domenico Casadei and Gabriele Rizzoli

Model Predictive Control of Power Converters, Chair: Po-Tai Cheng, Petros Karamanakos, Room: 202D 97

8:30AM *Constrained Long-Horizon Direct Model Predictive Control for Power Electronics*  
Petros Karamanakos, Tobias Geyer and Ralph Kennel

8:55AM *Thermal-based Finite Control Set Model Predictive Control for IGBT Power Electronic Converters*  
Johannes Falck, Markus Andresen and Marco Liserre

9:20AM *Modulated Model Predictive Control for Active Split DC-bus 4-leg Inverters*  
Stefano Bifaretti, Luca Tarisciotti, Alessandro Lidozzi, Sabino Pipolo, Luca Solero and Pericle Zanchetta

9:45AM *Computationally Efficient Sphere Decoding for Long-Horizon Direct Model Predictive Control*  
Petros Karamanakos, Tobias Geyer, Toit Mouton and Ralph Kennel

10:10AM *Fixed Frequency Finite-State Model Predictive Control for Indirect Matrix Converters with Optimal Switching Pattern*  
Jiaxing Lei, Luca Tarisciotti, Andrew Trentin, Pericle Zanchetta, Patrick Wheeler and Andrea Formentini

10:35AM *Improved Steady State Behavior of Finite Control Set Model Predictive Control applied to a Flying Capacitor Converter*  
Margarita Norambuena, Pablo Lezana and Jose Rodriguez

Reluctance Machines, Chair: Akira Chiba, Yun Wei Li, Room: 102B 98

8:30AM *A new application and experimental validation of moulding technology for Ferrite Magnet Assisted Synchronous Reluctance Machine*  
Qian Wu, Kaiyuan Lu, Keld Folsach Rasmussen and Peter Omand Rasmussen

8:55AM *Magnetic Field Analytical Computation in Synchronous Reluctance Machines Considering the Iron Saturation*  
Hanafy Mahmoud, Nicola Chiodetto and Nicola Bianchi

9:20AM *Performance Comparison of Short Pitched and Full Pitched Switched Reluctance Machines for Off-Road Vehicle Applications*  
Tausif Husain, Wasi Uddin and Yilmaz Sozer

9:45AM *A Fault Tolerant Machine Drive based on Permanent Magnet Assisted Synchronous Reluctance Machine*  
Bo Wang, Jiabin Wang, Antonio Griffo, Zhigang Sun and Ellis Chong

10:10AM *A General Approach for the Analysis and Comparison of Hybrid Synchronous Machines With Single-Axis or Bi-Axial Excitation*  
Fabio Giulii Capponi, Gabriele Borocci, Ion Boldea, Giulio De Donato and Federico Caricchi

10:35AM *Flux Modulation Principles of DC-Biased Sinusoidal Current Vernier Reluctance Machines*  
Shaofeng Jia, Ronghai Qu, Dawei Li and Jian Li

Materials and Manufacturing Issues of Electric Machines, Chair: Aldo Boglietti, Daniel Ludois, Room: 101A 99

8:30AM *Stator Lamination Geometry Influence on the Building Factor of Synchronous Reluctance Motor Cores*  
Andrea Cavagnino and Zbigniew Gmyrek

8:55AM *Influence of PM Coating on PM Magnetization State Estimation Methods Based on Magnetoresistance Effect*  
Daniel Fernandez, David Reigosa, Juan Manuel Guerrero, Zi-Qiang Zhu and Fernando Briz

9:20AM *Investigation of the Impact of Production Processes on Iron Losses of Laminated Stator Cores for Electric Machines*  
Marc Veigel, Alexandra Kraemer, Gisela Lanza and Martin Doppelbauer

9:45AM *Influence of Manufacturing Tolerances on Cogging Torque in Interior Permanent Magnet Machines with Eccentric and Sinusoidal Rotor Contours*  
Xiao Ge and Z. Q. Zhu

10:10AM *A Practical Approach of Electromagnetic Analysis with the Effect of the Residual Strain due to Manufacturing Processes*  
Hiroyuki Sano, Katsuyuki Narita, Eri Zeze, Takashi Yamada, Kazuki Ueta and Kan Akatsu

10:35AM *Investigation of Emerging Magnetic Materials for Application in Axial-Flux PM Machines*  
Solmaz Kahourzade, Nesimi Ertugrul and Wen Soong

Induction Motor Drives, Chair: Sertac Bayhan, Di Pan, Room: 101B 100

8:30AM *A Compact Active Filter to Eliminate Common-Mode Voltage in a SiC-based Motor Drive*  
Kellan Euerle, Kartik Iyer, Eric Severson, Rohit Baranwal, Saurabh Tewari and Ned Mohan

8:55AM *Stator Inter-Turn Fault Detection for Seamless Fault-Tolerant Operation of Five-Phase Induction Motors*  
Vivek M. Sundaram and Hamid A. Toliyat

9:20AM *Rotor Temperature Estimation in Doubly-Fed Induction Machines Using Rotating High Frequency Signal Injection*  
David Reigosa, Juan Manuel Guerrero and Fernando Briz

9:45AM *Maximum Torque Output for Volts/Hz Controlled Induction Machines in Flux-weakening Region*  
Kai Wang, Kevin Lee, Wenxi Yao and Fayi Chen

10:10AM *Performance Investigation of Selected Prediction Vectors Based FS-PTC for 3L-NPC Inverter Fed Motor Drive*  
Md Habibullah, Dylan Dah-Chuan Lu, Dan Xiao and Muhammed Fazlur Rahman

10:35AM *Inverter-fed Drive Stator Insulation Monitoring based on Reflection Phenomena Stimulated by Voltage Step Excitation*  
Clemens Zoeller, Markus Vogelsberger and Thomas Wolbank

PM and IPM Motor Drives I, Chair: Nicola Bianchi, Prerit Pramod, Room: 101CD 101

8:30AM *maximum torque per ampere control in stator flux linkage synchronous frame for DTC-based PMSM drives without using q-axis inductance*  
Atsushi Shinohara, Yukinori Inoue, Shigeo Morimoto and Masayuki Sanada

8:55AM *A Novel Direct Torque Control Strategy for Interior Permanent Magnet Synchronous Motors Driven by a Three-level Simplified Neutral Point Clamped Inverter*  
Tung Ngo, Gilbert Foo, Craig Baguley, Deepu Mohan and Xinan Zhang

9:20AM *Fault Tolerant Capability of Deadbeat - Direct Torque and Flux Control for Three-Phase PMSM Drives*  
Mario Pulvirenti, Giuseppe Scarcella, Giacomo Scelba and Robert D. Lorenz

9:45AM *Online MTPA Control for Salient-Pole PMSMs Using Square-Wave Current Injection*  
Yue Zhao

10:10AM *Automatic MTPA Tracking in IPMSM Drives: Loop Dynamics, Design and Auto-Tuning*  
Nicola Bedetti, Sandro Calligaro, Christian Olsen and Roberto Petrella

10:35AM *Reduction of Unbalanced Axial Magnetic Force in Post-fault Operation of a Novel Six-phase Double-stator Axial Flux PM Machine Using Model Predictive Control*  
Hanxiao Lu, Jian Li, Ronghai Qu, Linyuan Xiao and Donglin Ye

Wide Bandgap Applications: Comparative Studies, Chair: David Reusch, Robert Pilawa-Podgurski, Room: 202C 102

8:30AM *Comparative Evaluation of 15 kV SiC IGBT and 15 kV SiC MOSFET for 3- Phase Medium Voltage High Power Grid Connected Converter Applications*  
Sachin Madhusoodhanan, Krishna Mainali, Awneesh Tripathi, Arun Kadavelugu, Kasunaidu Vechalapu, Dhaval Patel and Subhashish Bhattacharya

8:55AM *Comparison between SiC and GaN devices in 6.78 MHz 2.2 kW resonant inverters for wireless power transfer*  
Jungwon Choi, Daisuke Tsukiyama and Juan Rivas

9:20AM *Comparison of GaN FET and Si MOSFET Based Vienna Rectifiers*  
Yutong Zhu and Yehui Han

9:45AM *Comparison of GaN and SiC Power Devices in Application to MW-scale Quasi-Z-Source Cascaded Multilevel Inverters*  
Haiyu Zhang, Baoming Ge, Yushan Liu, Bayhan Sertac, Robert S. Balog and Haitham Abu-Rub

10:10AM *Comparison of deadtime effects on the performance of dc-dc converters with GaN FETs and Silicon MOSFETs*  
John Glaser and David Reusch

10:35AM *Characterization and Comparison of Latest Generation 900-V and 1.2-kV SiC MOSFETs*  
Alinaghi Marzoughi, Rolando Burgos and Dushan Boroyevich

Gate Drive Techniques I, Chair: Prasad Enjeti, Daniel Costinett, Room: 102A 104

8:30AM *High Speed Optical Gate Driver for Wide Band Gap Power Transistors*  
Davy Colin and Nicolas Rouger

8:55AM *Reduction of oscillations in a GaN bridge leg using active gate driving with sub-ns resolution, arbitrary gate-impedance patterns*  
Harry C. P. Dymond, Dawei Liu, Jianjing Wang, Jeremy J. O. Dalton, Neville McNeill, Dinesh Pamunuwa, Simon J. Hollis and Bernard H. Stark

9:20AM *Design Considerations and Comparison of High-speed Gate Drivers for Si IGBT and SiC MOSFET Modules*  
Shan Yin, King Jet Tseng, Pengfei Tu, Rejeki Simanjorang and Amit K. Gupta

9:45AM *Active Gate Driving Technique for a 1200 V SiC MOSFET to Minimize Detrimental Effects of Parasitic Inductance in the Converter Layout*  
Parthasarathy Nayak and Kamalesh Hatua

10:10AM *Comprehensive Evaluation of Gate Boost Driver for SiC-MOSFETs*  
Koji Yamaguchi and Yukihiko Sato

10:35AM *Gate Driver for the Active Thermal Control of a DCDC GaN based Converter*  
Pramod Kumar Prasobhu, Giampaolo Buticchi, Stephan Brueske and Marco Liserre

Wireless Power Transfer II, Chair: Khurram Afridi, Huai Wang, Room: 202B 105

8:30AM *A Mistuning-Tolerant and Controllable Power Supply for Roadway Wireless Power Systems*  
Abhilash Kamineni, Grant A. Covic and John T. Boys

8:55AM *Power Converter with Novel Transformer Structure for Wireless Power Transfer Using a DD2Q Power Receiver Coil Set*  
Guangjie Ke, Qianhong Chen, Wei Gao, Siu-Chung Wong and Chi.K. Tse

9:20AM *A Wireless Power Transfer System with a Double Current Rectifier for EVs*  
Toshiyuki Fujita, Tomio Yasuda and Hirofumi Akagi

9:45AM *Hybrid Control of Inductive Power Transfer Charger for Electric Vehicles using LCCL-S Resonant Network in Limited Operating Frequency Range*  
Jongeun Byeon, Minhyuck Kang, Minkook Kim, Dong-Myoung Joo and Byoung Kuk Lee

10:10AM *Research on Seamless Transfer from CC to CV Modes for IPT EV Charging System Based on Double-sided LCC Compensation Network*  
Lu Jiang-Hua, Zhu Guo-rong, Lin Peng, Li Xiao-Kun, Li Wen-jing, Wong Siu-Chung and Jiang Jing

10:35AM *Closed-Loop Control Design for WPT System Using Power and Data Frequency Division Multiplexing Technique*  
Zhongnan Qian, Ruichi Wang, Zhikun Wang, Jin Du, Jiande Wu and Xiangning He

Tuesday, September 20, 11:00AM-12:30PM

Poster Session: Renewable and Sustainable Energy Applications, Chair: Euzeli Santos Jr., Rajendra Prasad Kandula, Room: Exhibit Hall 106

P1901 *Power Balance Control and Circulating Current Suppression for MMC based EV Integration System Considering Users Requirement*  
Meiqin Mao, Tinghuan Tao, Yong Ding, Liuchen Chang and Nikos Hatziargyriou

P1902 *Optimal Sizing of Energy Storage for PV Power Ramp Rate Regulation*  
Qian Zhao, Kunna Wu and Ashwin M Khambadkone

P1903 *Model-Based Adaptive Control of a Hydraulic Wind Power System*  
Masoud Vaezi and Afshin Izadian

P1904 *Sensorless speed control of a small wind turbine using the rectifier voltage ripple*  
Juan Manuel Guerrero, Carlos Lumbreras, David Reigosa, Cristian Blanco and Fernando Briz

P1905 *Maximum Power Point Tracking (MPPT) of Sensorless PMSG Wind Power System*  
Yu Zou and Jiangbiao He

P1906 *Current/Voltage Sensor Fault Detection and Isolation in Wind Energy Conversion Systems Based on Power Balance*  
Haibo Li, Liyan Qu, Wei Qiao and Chun Wei

P1907 *Quasi-Z-Source-Based Multilevel Inverter for Single-Phase Photo Voltaic Applications*  
Aida Gorgani, Malik Elbuluk, Yilmaz Sozer and Haitham Abu-Rub

P1908 *Dual Buck Based Power Decoupling Circuit for Single Phase Inverter/Rectifier*  
Xiao Li, Shunlong Xiao, Haiyu Zhang, Robert S. Balog and Baoming Ge

Poster Session: Smart Grid & Utility Applications, Chair: Johan Enslin, Euzeli Santos Jr., Room: Exhibit Hall 107

P2101 *Design and Development of a True Decentralized Control Architecture for Microgrid*  
Abedalsalam Bani-Ahmed, Adel Nasiri and Hosseini Hossein

P2102 *Modeling and Control of a Synchronous Generator in an AC Microgrid Environment*  
Luke Weber, David Hyypio, William Dittman and Adel Nasiri

P2103 *State Estimation of Power Systems with Interphase Power Controllers Using the WLS Algorithm*  
Mohammad Amin Chitsazan and Andrzej M Trzynadlowski

P2104 *A Novel T-Type Half-Bridge Cell for Modular Multilevel Converter with DC Fault Blocking Capability*  
Fangzhou Zhao, Guochun Xiao, Daoshu Yang, Min Liu, Xiaoli Han and Baojin Liu

P2105 *A Distributed Control Method for Power Module Voltage Balancing of Modular Multilevel Converters*  
YongJie Luo, YaoHua Li, ZiXin Li and Ping Wang

P2106 *Control Method of Single-phase Inverter Based Grounding System in Distribution Networks*  
Wen Wang, Yan Lingjie, Xiangjun Zeng, Zhao Xin, Wei Baoze and Guerrero Josep M.

Poster Session: Transportation Electrification Applications, Chair: Jin Wang, Yaosuo "Sonny" Xue, Room: Exhibit Hall 108

P2301 *A Novel Energy Balanced Variable Frequency Control for Input-Series-Output-Parallel Modular EV Fast Charging Stations*  
Qi Tian, Hua Bai, Huang Alex, Teng Hui and Lu Juncheng

P2302 *An Adaptive Charging Control Strategy For Ultracapacitor Light Rail Vehicles*  
Zhou Rong, Huang Zhiwu, Li Heng, Wu Zhihui and Peng Jun

P2303 *A High Power Density Drivetrain-Integrated Electric Vehicle Charger*  
Usama Anwar, Hyeokjin Kim, Hua Chen, Robert Erickson, Dragan Maksimovic and Khurram Afridi

P2304 *Railway Power Conditioner Based on Delta-connected Modular Multilevel Converter*  
Jiao Shang, NingYi Dai, BaoAn Wang and Hao Chen

P2305 *Dynamic Study of Electromechanical Interaction in Marine Propulsion*  
Jishnu Kavil Kambrath, Aaron Alexander Ayu, Youyi Wang, Yong-Jin Yoon, Xiong Liu, Chandana Jayampathi Gajanayake and Amit Kumar Gupta

P2306 *Model-based Control Design for a Battery/Ultracapacitor DC-DC Converter System*  
Anantharaghavan Sridhar, Phil Kollmeyer and Thomas Jahns

P2307 *Sliding Model Control Based On Estimation Of Optimal Slip Ratio For Railway Wheel Slide Protection Using Extremum Seeking*  
Qing Peng, Jianfeng Liu, Zhiwu Huang, Weirong Liu and Heng Li

P2308 *Evaluation of Negative-Sequence-Current Compensators for High-Speed Electric Railways*  
Antonios Antonopoulos and Jan Svensson

Poster Session: Power Converter Topologies, Chair: Pradeep S. Shenoy, Leon M Tolbert, Room: Exhibit Hal 110

P2501 *A ZVS Integrated Single-Input-Dual-Output DC/DC Converter for High Step-up Applications*  
Ming Shang and Wang Haoyu

P2502 *A Survey on Voltage Boosting Techniques for Step-Up DC-DC Converters*  
Mojtaba Forouzesh, Yam P. Siwakoti, Saman A. Gorji, Frede Blaabjerg and Brad Lehman

P2503 *Analysis and Design of a Current fed Non-isolated Buck-Boost DC-DC Converter*  
Ashok Kumar, Roja Peri and Parthasarathi Sensarma

P2504 *Impulse Commutated Current-fed Three-phase Modular DC/DC Converter for Low Voltage High Current Applications*  
Akshay Rathore and Radha Sree Krishna Moorthy

P2505 *Comparative evaluation of capacitor-coupled and transformer-coupled dual active bridge converters*  
Parikshith Channegowda and Giri Venkataramanan

P2506 *Planar Transformer Winding Technique for Reduced Capacitance in LLC Power Converters*  
Mohammad Ali Saket Tokaldani, Navid Shafiei and Martin Ordonez

P2507 *Topology and Controller of an Isolated Bi-Directional AC-DC Converter for Electric Vehicle*  
Beham Koushki, Praveen Jain and Alireza Bekhshai

P2508 *High Efficiency LLC DCX Battery Chargers with Sinusoidal Power Decoupling Control*  
Dong-Jie Gu, Zhiliang Zhang, Yaqi Wu, Dong Wang, Handong Gui and Li Wang

P2509 *PWM Strategies with Duality between Current and Voltage Source AC/DC Converters for Suppressing AC Harmonics or DC Ripples*  
Junpei Isozaki, Kazuma Suzuki, Wataru Kitagawa and Takaharu Takeshita

P2510 *Analytical Expression for Harmonic Spectrum of Regular Sampled Space Vector Modulated Rectifier Connected to IPM Generator*  
Jian Zhang, XuHui Wen, JinLong Li, Youlong Wang and WenShan Li

P2511 *A Systematic Topology Generation Method for Dual-Buck Inverters*  
Li Zhang, Tao Zhu, Lin Chen and Kai Sun

P2512 *Analysis and Control of Decentralized PV Cascaded Multilevel Modular Integrated Converters*  
David Scholten, Nesimi Ertugrul and Wen Soong

P2513 *Experimental Study of a SiC MOSFET based Single Phase Inverter in UPS Applications*  
Cheng Luo, Xinyu Wang, Tianyang Jiang, Richard Feng, Huiting Xin and Han Li

P2514 *Performance Analysis of a flexible multi-level converter for high voltage photovoltaic grid-connected power system*  
Lu Zhou, Li Wuhua, Hu Senjun, Luo Haoze, He Xiangning, Cao Fengwen, Zhang Chaoshan and Du Jiyuan

P2515 *Circulating Current Control for Carrier-Based Discontinuous Modulation in Inverters with Parallel Legs*  
Andre Nicolini, Antonio Ricciotti, Fernanda Carnielutti and Humberto Pinheiro

P2516 *A Phase-Shift PWM-Controlled ZVS Boost Full-Bridge AC-AC Converter for High-Frequency Induction Heating Applications*  
Shuichi Sakamoto, Tomokazu Mishima and Chiaki Ide

P2517 *Control Approach for a Class of Modular Multilevel Converter Topologies*  
Dennis Karwatzki and Axel Mertens

Poster Session: Control, Modelling and Optimization of Power Converters, Chair: Pericle Zanchetta, Luca Solero, Room: Exhibit Hall 112

P2701 *Digital Autotuning Controller for Point-of-Load Converter Based on Non-Intrusive Start-up Transient Observer*  
M. Ali, K. H. Loo and Y. M. Lai

P2702 *Control of D-STATCOM During Unbalanced Grid Faults Based on DC Voltage Oscillation and Peak Current Limitations*  
Arash Khoshooei, Javad Moghani, Jafar Milimonfared, Alvaro Luna, Ignacio Candela and Pedro Rodriguez

P2703 *Staircase Modulation of Modular Multilevel Converters with Minimal Total Harmonic Distortion and Maximal Number of Output Voltage Levels*  
Sufei Li, Yi Deng and Ronald Harley

P2704 *FPGA Implementation of Model Predictive Direct Current Control*  
Joel Vallone, Tobias Geyer and Eduardo Rath Rohr

P2705 *Active Damping of LC Resonance for Paralleled Indirect Matrix Converter Based on Cascaded Control*  
Yang Xiao, Zheng Wang, Shuai You, Ming Cheng and Liang Xu

P2706 *Virtual Circuit Design of Grid-Connected Half-Bridge Converters with Higher-Order Filters*  
Korawich Niyomsatian, Piet Vanassche, Bruno Hendrickx, Peter Tant, Jeroen Van den Keybus and Johan Gyselinck

P2707 *Commutation Technique for High Frequency Link Inverter without Operational Limitations and Dead Time*  
Minjeong Kim and Robert S. Balog

P2708 *Research on the Current Control method of N-paralleled Converter System for the High-Power Inductor Tester*  
Cheng Nie, Wanjun Lei, Huajia Wang, Mingfeng Chen and Yue Wang

P2709 *Modeling and Bifurcation Analysis of Converters with Power Semiconductor Filter*  
Wing-to Fan and Shu-hung Chung

P2710 *Suppression of Circulating Current in Paralleled Inverters with Isolated DC-link*  
Hyun-Sam Jung, Jeong-Mock Yoo, Seung-Ki Sul, Hak-Jun Lee and Chanook Hong

P2711 *Small-Signal Model for the ISOP DC-DC Converters in the 5-Level T-Rectifier*  
Marco Di Benedetto, Alessandro Lidozzi, Luca Solero, Fabio Crescimbini and Petar Grbovic

P2712 *DC Bus Splitting Voltage Feedforward Injection Method for Virtually-Grounded Three-Phase Inverter*  
He Yuanbin, Chung Shu-hung, Ho Ngai-man, Wu Weimin and Fan Wing-to

P2713 *High Performance SiC Power Block for Industry Applications*  
Xu She, Rajib Datta, Maja Harfman Todorovic, Gary Mandrusiak, Jian Dai, Tony Frangieh, Philip Cioffi, Brian Rowden and Frank Mueller

P2714 *Switching Angles Generation for Selective Harmonic Elimination by Using Artificial Neural Networks and Quasi-Newton Algorithm*  
Kehu Yang, Jun Hao and Yubo Wang

P2715 *Minimum RMS Current Operation of the Dual-Active Half-Bridge Converter using Three Degree of Freedom Control*  
Shiladri Chakraborty, Shailesh Tripathy and Souvik Chattopadhyay

Poster Session: Electrical Machines, Chair: Bruno Lequesne, Mohammad Islam, Room: Exhibit Hall 115

P2901 *Comparison of Torque Characteristics in Permanent Magnet Synchronous Machine with Conventional and Herringbone Rotor Step Skewing Techniques*  
Weizhong Fei, Patrick Chi Kwong Luk and Wenyi Liang

P2902 *Six-Leg Dc-Link Rectifier/Inverter for Two-Phase Machines*  
Nayara Brandao de Freitas, Cursino Brandao Jacobina and Alexandre Cunha Oliveira

P2903 *RSM-DE-ANN Method for Sensitivity Analysis of Active Material Cost in PM Motors*  
Alireza Fatemi, Dan Ionel, Nabeel Demerdash, Steve Stretz and Thomas Jahns

P2904 *Modeling, simulation and performance evaluation of caged permanent magnet motors fed by variable speed drives (VSDs)*  
Sara Ahmed, Darren Tremelling, Zi-Ang (John) Zhang, Nicolas Frank, Robert McElveen and Kim Hongrae

P2905 *An Improved Conformal Mapping Aided Field Reconstruction Method for Modeling of Interior Permanent Magnet Synchronous Machines*  
Lei Gu, Mehdi Moallem, Shiliang Wang, Devendra Patil and Babak Fahimi

P2906 *Hybrid Excited Vernier PM Machines with Novel DC-Biased Sinusoidal Armature Current*  
Shaofeng Jia, Ronghai Qu, Jian Li, Dawei Li and Haiyang Fang

P2907 *Calculating the Electromagnetic Field and Losses in the End Region of Large Synchronous Generators under Different Operating Conditions with Three-Dimensional Transient Finite Element Analysis*  
Sufei Li, Noris Gallandat, J. Rhett Mayor and Ronald Harley

P2908 *Electrical Propulsion System Design of Chevrolet Bolt Battery Electric Vehicle*  
Faizul Momen, Khwaja Rahman, Yochan Son, Bonho Bae and Peter Savagian

P2909 *Optimizing PM Coverage Ratio in Flux Concentrating Axial Flux Machine*  
Minhyeok Lee, Kwanghee Nam and Jaehong Kim

P2910 *Detailed Analytical Modelling of Fractional-Slot Concentrated-Wound Interior Permanent Magnet Machines for Prediction of Torque Ripple*  
Mohammad Farshadnia, Muhammad Ali Masood Cheema, Rukmi Dutta, John Fletcher and Muhammed Fazlur Rahman

P2911 *A compact and light-weight generator for backpack energy harvesting*  
Siavash Pakdelian

P2912 *Suspension Loss Measurement and its Reduction in Single-Drive Bearingless Motor*  
Itsuki Shimura, Hiroya Sugimoto and Akira Chiba

P2913 *A Compact Single-Phase Adjustable-Voltage-Ratio Magnetoelectric Transformer*  
Haosen Wang, Liya Qu and Wei Qiao

P2914 *Analysis of Common Mode Circuit of BDFG-Based Ship Shaft Power Generation System*  
Hongbin Yang, Hua Lin, Xingwei Wang and Guangzhi Yao

P2915 *Replacing SPM by PMARel machines in low-speed high-torque applications*  
Nicola Bianchi, Alessandro Castagnini, Giulio Secondo and Pietro Savio Termini

P2916 *Rotor Eddy-Current Loss Minimization in High-Speed PMSMs*  
Haiyang Fang, Ronghai Qu, Jian Li and Bao Song

P2917 *Design and Analysis of Rotating Diode Rectifier for Wound-Rotor Synchronous Starter/Generator*  
Pang Ji, Weiguo Liu, Chenghao Sun, Jixiang Wang, Zan Zhang and Yu Jiang

P2918 *Stator Tooth and Rotor Pole Shaping for Low Pole Flux Switching Permanent Magnet Machines to Reduce Even Order Harmonics in Flux linkage*  
Dheeraj Bobba, Gerd Bramerdorfer, Yingjie Li, Timothy A. Burress and Bulent Sarlioglu

P2919 *Optimization of PM Volume in a PM-assisted Claw-Pole Motor for ISG Applications*  
Bonkil Koo, Jeongki Kwon and Kwanghee Nam

Poster Session: Electric Drives, Chair: Uday Deshpande, Gianmario Pellegrino, Room: Exhibit Hall 118

P3101 *Improved Model Predictive Current Control of Permanent Magnet Synchronous Machines with Fuzzy Based Duty Cycle Control*  
Amir Masoud Bozorgi, Mehdi Farasat and Seyyedmahdi Jafarishiadeh

P3102 *A Universal Restart Strategy for Induction Machines*  
Kibok Lee, Sara Ahmed and Srdjan Lukic

P3103 *Active Disturbance Rejection Control of Linear Induction Motor*  
Francesco Alonge, Maurizio Cirrincione, Filippo D'Ippolito, Marcello Pucci and Antonino Sferlazza

P3104 *Super-Twisting Algorithm Based Sliding-Mode Observer with Online Parameter Estimation for Sensorless Control of Permanent Magnet Synchronous Machine*  
Donglai Liang, Jian Li and Ronghai Qu

P3105 *High Dynamic Sensorless Control for PMSMs Based on Decoupling Adaptive Observer*  
Yongle Mao, Jiaqiang Yang, Tao Wang, Dejun Yin and Yangsheng Chen

P3106 *Position Sensorless Control of Switched Reluctance Motor Based on a Numerical Method*  
Fei Peng, Jin Ye and Ali Emadi

P3107 *Operating-Envelop-Expandable Control Strategy for Switched Flux Hybrid Magnet Memory Machine*  
Hui Yang, Heyun Lin, Z. Q. Zhu, Erxing Zhuang, Shuhua Fang and Yunkai Huang

Poster Session: Power Semiconductor Devices, Passive Components, Packaging, Integration, and Materials, Chair: Giovanna Oriti, Enrico Santi, Room: Exhibit Hall 119

P3301 *Modelling the closely coupled cascode switching process*  
Pablo F. Miaja, Sheng Jiang, Kean-Boon Lee, Peter A. Houston, Ivor Guiney, David J. Wallis, Colin J. Humphreys and Andrew J. Forsyth

P3302 *A 700-V Class Reverse-Blocking IGBT for Large Capacity Power Supply Applications*  
David Hongfei Lu, Hiromu Takubo, Hiroki Wakimoto, Toru Muramatsu and Haruo Nakazawa

P3303 *Efficiency and Electromagnetic Interference Analysis of Wireless Power Transfer for High Voltage Gate Driver Application*  
Jianyu Pan, Feng Qi, Haiwei Cai and Longya Xu

P3304 *Single Chip Enabled High Frequency Link based Isolated Bias Supply for Silicon Carbide MOSFET Six-Pack Power Module Gate Drives*  
Rui Gao, Li Yang, Wensong Yu and Iqbal Husain

P3305 *Reliability Assessment of SiC Power MOSFETs From The End Users Perspective*  
Vasilios Dimitris Karaventzas, Muhammad Nawaz and Francesco Iannuzzo

P3306 *Investigation of Collector Emitter Voltage Characteristics in Thermally Stressed Discrete IGBT Devices*  
Syed Huzaif Ali, Serkan Dusmez and Bilal Akin

Poster Session: Emerging Technologies and Applications, Chair: Jin Wang, Yaosuo "Sonny" Xue, Room: Exhibit Hall 120

P3501 *Transmission Characteristics Analysis of a Three-Phase Magnetically Coupled Resonant Wireless Power Transfer System*  
Jiang Chong, Liu Fuxin, Ruan Xinbo and Chen Xuling

P3502 *Synthesis of Buck Converter Based Current Sources*  
Soumya Shubhra Nag and Santanu Mishra

P3503 *A Model for Coupling Under Coil Misalignment for DD Pads and Circular Pads of WPT Systems*  
Guangjie Ke, Qianhong Chen, Ligang Xu, Siu-Chung Wong and Chi.K. Tse

P3504 *Comprehensive Dynamic Modeling of a Solid-state Transformer Based Power Distribution System*  
Md Tanvir Arafat Khan, Alireza Afiat Milani, Aranya Chakrabortty and Iqbal Husain

P3505 *Capability, Compatibility, and Usability Evaluation of Hardware-in-the-Loop Platforms for DC-DC Converter*  
Shawn Maxwell, S M Rakiul Islam, Md. Kamal Hossain and Sung Yeul Park

P3506 *A Single Stage AC/DC Converter for Low Voltage Energy Harvesting*  
Liang Yu and Haoyu Wang

Tuesday, September 20, 3:00PM-4:30PM

Poster Session: Renewable and Sustainable Energy Applications, Chair: Euzeli Santos Jr., Johan Enslin, Room: Exhibit Hall 121

P3701 *Dynamic Battery Operational Cost Modeling for Energy Dispatch*  
Qian Zhao, Aniq Ahsan, Ashwin M. Kambadkone and Meng Hwee Chia

P3702 *A Low Voltage Ride Through Control Strategy for Energy Storage Systems*  
Yeongsu Bak, June-Seok Lee and Kyo-Beum Lee

P3703 *Experimental Validation of the Solid State Substation with Embedded Energy Storage Concept*  
Christian Klumpner, Mohamed Rashed, Dipankar De, Chintan Patel, Ponggorn Kulsangcharoen and Greg Asher

P3704 *Understanding Dynamic Model Validation of a Wind Turbine Generator and a Wind Power Plant*  
Eduard Muljadi, Yingchen Zhang, Vahan Gevorgian and Dmitry Kosterev

P3705 *A Brushless Doubly-fed Generator Based on Permanent Magnet Field Modulation for Wind Power Generation*  
Yongjiang Jiang, Jianzhong Zhang, Shuai Xu and Xing Hu

P3706 *Robust Sliding Mode Control for Permanent Magnet Synchronous Generator-Based Wind Energy Conversion Systems*  
Patrick Gu, Xin Wang and Max Reitz

P3707 *A Partially-Rated Active Filter Enabled Power Architecture to Generate Oscillating Power From Wave Energy Converter*  
Samir Hazra, Prathamesh Kamat and Subhashish Bhattacharya

P3708 *Hybrid Energy Storage System Comprising of Battery and Ultra-capacitor For Smoothing of Oscillating Wave Energy*  
Samir Hazra and Subhashish Bhattacharya

Poster Session: Smart Grid & Utility Applications, Chair: Johan H Enslin, Euzeli Santos Jr., Room: Exhibit Hall 123

P3901 *A Series-LC-Filtered Active Trap Filter for High Power Voltage Source Inverter*  
Haofeng Bai, Xiongfei Wang, Poh Chiang Loh and Frede Blaabjerg

P3902 *Constant DC-Capacitor Voltage-Control-Based Strategy for Harmonics Compensation of Smart Charger for Electric Vehicles in Single-Phase Three-Wire Distribution Feeders With Reactive Power Control*  
Fuka Ikeda, Kei Nishikawa, Hiroaki Yamada, Toshihiko Tanaka and Masayuki Okamoto

P3903 *A Series Active Damper with Closed-loop Control for Stabilizing Single-phase Power-Electronics-Based Power System*  
Dapeng Lu, Xiongfei Wang, Haofeng Bai and Frede Blaabjerg

P3904 *A Grid-Interfaced Test System for Modeling of NiMH Batteries in a Battery-Buffered Smart Load Application*  
Ahmed Zurfi and Jing Zhang

P3905 *Impedance-Based Stability Analysis of DFIG*  
Tianyi Wang, Yi Xiao, Xueguang Zhang and Dianguo Xu

P3906 *Online Variation of Wind Turbine Controller Parameters for Mitigation of SSR in DFIG based Wind Farms*  
Selam Chernet, Massimo Bongiorno, Gert Karmisholt Andersen, Torsten Lund and Philip Carne Kjaer

P3907 *Three-Phase Single Stage Boost Inverter for Direct Drive Wind Turbines*  
Akanksha Singh and Behrooz Mirafzal

P3908 *Secondary Side Modulation of a Single-stage Isolated High-frequency Link Microinverter with a Regenerative Flyback Snubber*  
Nareshkumar Kummari, Shiladri Chakraborty and Souvik Chattopadhyay

P3909 *Frequency Characterization of Type-IV Wind Turbine Systems*  
Nicolas Espinoza, Bongiorno Massimo and Carlson Ola

Poster Session: Datacenters and Telecommunication Applications, Chair: Jin Wang, Yaosuo "Sonny" Xue, Room: Exhibit Hall 124

P4101 *Reliablity Assessment of Fuel Cell System - A Framework for Quantitative Approach*  
Shinae Lee, Dao Zhou and Huai Wang

P4102 *New Soft-Switched Multi-Input Converters with Integrated Active Power Factor Correction for Hybrid Renewable Energy Applications*  
Sanjida Moury, John Lam, Vineet Srivastava and Church Ron

P4103 *FPGA Based Implementation of Control for Series Input Boost Pre-regulator Under Unequal Loading*  
Anwesha Mukhopadhyay and Santanu Mishra

Poster Session: Transportation Electrification Applications, Chair: Jin Wang, Yaosuo "Sonny" Xue, Room: Exhibit Hall 125

P4301 *Separating Key Less Well-Known Properties of Drive Profiles that Affect Lithium-ion Battery Aging by Applying the Statistical Design of Experiments*  
Ruxiu Zhao, Larry Juang, Robert Lorenz and Thomas Jahns

P4302 *Performance Degradation of Thermal Parameters during Cycle Ageing of NMC-based Lithium Ion Battery Cells*  
Tiberiu Stanciu, Daniel Stroe, Maciej Swierczynski, Nerea Nieto, Jon Gastelurrutia Roteta, Jean-Marc Timmermans and Remus Teodorescu

P4303 *Investigation of Current Sharing and Heat Dissipation in Parallel-Connected Lithium-Ion Battery Packs*  
Yichao Zhang, Ruxiu Zhao, Jacob Dubie, Larry Juang and Thomas Jahns

P4304 *A Cooperative Charging Strategy for Onboard Supercapacitors of Catenary-Free Trams*  
Heng Li, Jun Peng, Rong Zhou, Zhihui Wu, Zhiwu Huang and Jianping Pan

P4305 *A High Frequency Zero-Voltage-Transition (ZVT) Synchronous Buck Converter for Automotive Applications*  
Chenhao Nan and Raja Ayyanar

P4306 *The Dual-Channel Magnetically Integrated Chargers for Plug-in Electric Vehicles*  
Bochen Liu, Zheng Wang, Yue Zhang, Ming Cheng and Liang Xu

P4307 *Power-Line Impedance Modeling of Tractor-Trailer System*  
Iftekhar Hasan, Aparna Saha, Mohamad Abd Elmutalab, Ibrahem Amr, Philip Kasper, Yilmaz Sozer and Marv Hamdan

Poster Session: Power Converter Topologies, Chair: Pradeep S. Shenoy, Leon M Tolbert, Room: Exhibit Hall 126

P4501 *An Interleaved 1-to-6 Step-Up Resonant Switched-Capacitor Converter Utilizing Split-Phase Control*  
Andrew Stillwell, Derek Heeger, Christopher Meyer, Sarah Bedair and Robert Pilawa-Podgurski

P4502 *Boost Composite Converter Design Based On Drive Cycle Weighted Losses in Electric Vehicle Powertrain Applications*  
Hyeokjin Kim, Hua Chen, Robert Erickson and Maksimovic Dragan

P4503 *Design of a Four-Phase Interleaved Boost Circuit with Closed-Coupled Inductors*  
Daigoro Ebisumoto, Masataka Ishihara, Shota Kimura, Wilmar Martinez, Noah Mostafa, Masayoshi Yamamoto and Jun Imaoka

P4504 *Hybrid DC-DC Buck Converter with Active Switched Capacitor Cell and Low Voltage Gain*  
Mauricio Dalla Vecchia and Telles Lazzarin

P4505 *High Gain Resonant Boost Converter For PV Micro- Converter System*  
Sachin Jain, Swami Satish Betha and Jih-Sheng (Jason) Lai

P4506 *Design of Two-Switch Flyback Power Supply Using 1.7 kV SiC Devices for Ultra-Wide Input-Voltage Range Applications*  
Gabriele Rizzoli, Jun Wang, Zhiyu Shen, Rolando Burgos, Dushan Boroyevich and Luca Zarri

P4507 *A Single-Stage Interleaved LLC PFC Converter*  
Raed Saasaa, Wilson Eberle and Mohammed Agamy

P4508 *Medium Voltage AC-DC Rectifier for Solid State Transformer (SST) Based on an Improved Rectifier Topology*  
Qianlai Zhu, Li Wang, Xijun Ni, Liqi Zhang, Wensong Yu and Alex Q. Huang

P4509 *Microcontroller-Based MHz Totem-Pole PFC with Critical Mode Control*  
Zhengrong Huang, Zhengyang Liu, Qiang Li and Fred Lee

P4510 *Three-Phase Isolated DCM SEPIC Converter for High Voltage Applications*  
Gabriel Tibola, Erik Lemmen and Ivo Barbi

P4511 *Single Phase Precharge Control Method for Active Front End Rectifier*  
Lixiang Wei, Zeljko Jankovic, Yogesh Patel and Jiangang Hu

P4512 *Adaptive Controlled-type Zero-voltage-switching Inverters with Bandwidth Limitation*  
Dehua Zhang, Jiali Wang and Zhengyu Lv

P4513 *Half Bridge NPC Inverter and Its Three Phase Application with Constant Common Mode Voltage*  
Liwei Zhou, Feng Gao, Chongsheng Jia and Tao Xu

P4514 *Interleaved Auxiliary Resonant Snubber for High-Power, High-Density Applications*  
Rachael Born, Lanhua Zhang, Yu Wei, Qingqing Ma and Jason (Jih-Sheng) Lai

P4515 *Three-Phase Four-Wire Inverters Based on Cascaded Three-Phase Converters with Four and Three Legs*  
Joao Paulo Ramos Agra Mello, Cursino Bradao Jacobina and Mauricio Beltrao Rossiter Correa

P4516 *Optimal Switching Counts Modulation of H7 Current Source Inverter*  
Weiqi Wang, Feng Gao, Lei Zhang, Chen Mengxing and Liwei Zhou

P4517 *Cuk-Based Universal Converters in Discontinuous Conduction Mode of Operation*  
Mahshid Amirabadi

P4518 *Neutral Points Voltage Balancing Control of a Four-level pi-type Converter*  
Bosen Jin and Xibo Yuan

P4519 *A Novel Three-Phase Multilevel Diode-Clamped Inverter Topology with Reduced Device Count*  
Aparna Saha, Ali Elrayyah and Yilmaz Sozer

P4520 *Maximum Boost Space Vector Modulated Three-Phase Three-Level Neutral-Point-Clamped Quasi-Z-Source Inverter*  
Prasanth Sundararajan, Mohamed Sathik Mohamed Halick, Aaron Alexander Ayu, Tan Chuan Seng and Suresh Kumar K. S.

Poster Session: Control, Modelling and Optimization of Power Converters, Chair: Pericle Zanchetta, Luca Solero, Room: Exhibit Hall 129

P4701 *High Dynamic and Static Performance FCS-MPC Strategy for Static Power Converters*  
Rodrigo Mendez, Daniel Sbarbaro and Jose Espinoza

P4702 *New Logic-Form-Equation Based Active Voltage Control for Four-Level Flying Capacitor Multicell (FCM) Converter*  
Arash Khoshkbar Sadigh, Vahid Dargahi and Keith Corzine

P4703 *Experimental Evaluations of Thinned-Out and PDM Controlled Class-E Rectifier*  
Akane Iwasaki, Tomoharu Nagashima and Hiroo Sekiya

P4704 *Variable Slope External Ramp to Improve the Transient Performance in Constant On-Time Current Mode Control*  
Syed Bari, Brian Cheng, Qiang Li and Fred Lee

P4705 *PWM Methods for High Frequency Voltage Link Inverter Commutation*  
Minjeong Kim, Mostafa Mosa and Robert S. Balog

P4706 *Switching Pattern of a Modular Voltage Balancing Circuit for Battery Cells*  
Atrin Tavakoli, Sayed Ali Khajehoddin and John Salmon

P4707 *Steady State Impedance Estimation of a Weak Grid to Assist Optimal Current Injection for Minimal Power Losses*  
Akrama Khan, Azeem Khan and Michel Malengret

P4708 *A Single-phase Unified Power Quality Conditioner with An Enhanced Repetitive Controller*  
Dang-Minh Phan, Cong-Long Nguyen and Hong-Hee Lee

P4709 *Single-Phase Universal Active Power Filter Based on AC/AC Converters*  
Phelipe Leal Serafim Rodrigues, Cursino Brandao Jacobina and Mauricio Beltrao de Rossiter Correa

P4710 *Circulating Resonant Current Between Integrated Half-Bridge Modules with Capacitor for Inverter Circuit Using SiC-MOSFET*  
Takashi Hirao, Keiji Wada and Toshihisa Shimizu

P4711 *Computationally Efficient Event-Based Simulation of Switched Power Systems and AC Machinery*  
Christopher Wolf and Michael Degner

P4712 *Design Optimisation and Trade-offs in Multi-kW DC-DC Converters*  
James Scoltock, Gerardo Calderon-Lopez, Yiren Wang and Andrew Forsyth

P4713 *Switching frequency optimization for a Solid State Transformer with Energy Storage Capabilities*  
Pablo Garcia, Sarah Saeed, Hannes Schneider, Angel Navarro-Rodriguez and Jorge Garcia

P4714 *Lag-Free Terminal Voltage Sensing in Low-Pass Filtered PWM Converters*  
Adam Shea and Thomas Jahns

Poster Session: Electrical Machines, Chair: Bruno Lequesne, Mohammad Islam, Room: Exhibit Hall 131

P4901 *Cogging Torque Minimization with Rotor Tooth Shaping in Axial Flux-Switching Permanent Magnet Machine*  
Ju Hyung Kim, Yingjie Li, Emrah Cetin and Bulent Sarlioglu

P4902 *A 3D Printed Fluid Filled Variable Elastance Electrostatic Machine Optimized with Conformal Mapping*  
Baoyun Ge, Daniel Ludois and Ghule Aditya

P4903 *Effects of External Field Orientation on Permanent Magnet Demagnetization*  
Peng Peng, Han Xiong, Julia Zhang, Wanfeng Li, Franco Leonardi, Michael Degner, Chuanbing Rong, Feng Liang and Leyi Zhu

P4904 *Analytical Approach for Determining Inductance Matrix, Harmonic Voltage and Torque Ripple of Slotted PM Motors*  
Kahyun Lee and Jung-Ik Ha

P4905 *Cogging Torque Minimization in Transverse Flux Machines*  
Tausif Husain, Iftekhar Hasan, Yilmaz Sozer, Iqbal Husain and Eduard Muljadi

P4906 *Torque Ripple Reduction in a Flux-Switching Permanent Magnet Machine Targeted at Elevator Door Applications by Minimizing Space Harmonics*  
Hongsik Hwang, Dongjae Kim, Jin Hur and Cheewoo Lee

P4907 *On Saliency Enhancement of Salient Pole Wound Field Synchronous Machines*  
Wenbo Liu and Thomas.A Lipo

P4908 *Fast and Accurate Analytical Calculation of the Unsaturated Phase Inductance Profile of 6/4 Switched Reluctance Machines*  
Sufei Li, Shen Zhang, Thomas Habetler and Ronald Harley

P4909 *An Analytical Approach for Determining Harmonic Cusps and Torque Dips in Line Start Synchronous Reluctance Motors*  
Amir Negahdari, Vivek M. Sundaram and Hamid A. Toliyat

P4910 *Multi-Objective Design and Optimization of Generalized Switched Reluctance Machines with Particle Swarm Intelligence*  
Shen Zhang, Sufei Li, Jie Dang, Ronald G. Harley and Thomas G. Habetler

P4911 *Design and Comparison of Concentrated and Distributed Winding Synchronous Reluctance Machines*  
Bastian Lehner and Dieter Gerling

P4912 *Reduction in Torque and Suspension Force Ripples of an Axial-Gap Single-Drive Bearingless Motor*  
Junichi Asama, Kazumasa Takahashi, Takaaki Oiwa and Akira Chiba

P4913 *Advancements in High Power High Frequency Transformer Design for Resonant Converter Circuits*  
Ashraf Said Atalla, Mohammed Agamy, Mark Dame, Liwei Hao, Gary Dwayne Mandrusiak, Konrad Weeber and Yan Pan

P4914 *Active Damping of Ultra-fast Mechanical Switches for Hybrid AC and DC Circuit Breakers*  
Chang Peng, Landon Mackey, Iqbal Husain, Alex Huang, Bruno Lequesne and Roger Briggs

P4915 *A Diagnosis Procedure in Standalone Mode for Inter Turn Short Circuit Fault of PMSMs through Modified Self-Commissioning*  
Yuan Qi, Mohsen Zafarani and Bilal Akin

P4916 *Improved Condition Monitoring of the Faulty Blower Wheel Driven by Brushless DC Motor in Air Handler Unit (AHU)*  
Chen Jiang, Thomas Habetler and Wen-Ping Cao

P4917 *Mitigation Method of the Shaft Voltage according to parasitic capacitances of the PMSM*  
Jun-Kyu Park, Thusitha Wellawatta, Sung-Jin Choi and Jin Hur

P4918 *3-D Equivalent Magnetic Circuit Network for Precise and Fast Analysis of PM-assisted Claw-Pole Synchronous Motor*  
Jae-Han Sim, Dong-Gyun Ahn, Doo-Young Kim and Jung-Pyo Hong

P4919 *Superconducting and Conventional Electromagnetic Launch System for Civil Aircraft Assisted Take-off*  
Luca Bertola

P4920 *Design of Integrated Radial and Dual Axial-Flux Ferrite Magnet Synchronous Machine*  
Shoji Shimomura and Takatoshi Sunaga

Poster Session: Power Semiconductor Devices, Passive Components, Packaging, Integration, and Materials, Chair: Giovanna Oriti, Enrico Santi, Room: Exhibit Hall 135

P5101 *Comprehensive Evaluation of a Silicon-WBG Hybrid Switch*  
Amol Deshpande and Fang Luo

P5102 *Characterization of Power Capacitors on Practical Current Condition Using Capacitor Loss Analyzer*  
Hironori Nagasaki, Pin-Yu Huang and Toshihisa Shimizu

P5103 *A Practical Liquid-Cooling Design Method for Magnetic Components of EMI Filter in High Power Motor Drives*  
Jing Xue and Fred Wang

P5104 *Efficiency Modeling of Wireless Power Transfer ASICs Accounting for Layout Parasitics*  
Rosario Pagano, Siamak Abedinpour, Angelo Raciti and Salvatore Musumeci

P5105 *Direct Voltage Balancing for Series Connected IGBTs*  
Xueqiang Zhang, Jin Zhang and Patrick Palmer

Poster Session: Energy Efficiency Systems and Applications, Chair: Pericle Zanchetta, Mohammad Anwar, Room: Exhibit Hall 136

P5301 *Mitigation of Harmonics in Drilling Rigs using Shunt Active Power Filters*  
Muhammed Fasil Tp, Abdul R Beig, Rajasekharareddy Chilipi, Saikrishna Kanukollu, Naji Al Sayari and Khalifa Al Hosani

P5302 *Variable Switching Frequency Algorithm for Optimal Tradeoff between Switching Losses and Total Demand Distortion in Grid-Tied Three-Phase Voltage-Source Inverters*  
Hamzeh Jamal, Saher Albatran and Issam Smadi

P5303 *A Hybrid Model Predictive Charging Control Strategy for Ultracapacitors of Urban Rail Vehicles*  
Yuanjun Chen, Xiaoyong Zhang, Zhiwu Huang, Jun Peng, Zheng Xu and Yanhui Zhou

P5304 *A Universal-Input Single-stage AC-DC Converter for Twin-Bus Type High-Power LED applications*  
Hongbo Ma, Gang Chen, Yi Junhong, Meng Qingwei and Sha Deshang

P5305 *Control IC for TRIAC Dimming LED Driver with Quasi-Resonant Flyback Converter*  
Tsorng-Juu Liang, Shih-Wen Tsai, Kai-Hui Chen and Ta-Wei Huang

Poster Session: Emerging Technologies and Applications, Chair: Jin Wang, Yaosuo "Sonny" Xue, Room: Exhibit Hall 136

P5501 *Mutual Inductance Measurement for Power Device Package Using Time Domain Reflectometry*  
Kazunori Hasegawa, Keiji Wada and Ichiro Omura

P5502 *Synchronized triple bias-flip circuit for piezoelectric energy harvesting enhancement: operation principle and experimental validation*  
Yuheng Zhao and Junrui Liang

P5503 *Approaching Repetitive Short Circuit Tests on MW-Scale Power Modules by means of an Automatic Testing Setup*  
Paula Diaz Reigosa, Huai Wang, Francesco Iannuzzo and Frede Blaabjerg

P5504 *Cascaded Operation of SiC JFETs in Medium Voltage Solid State Circuit Breakers*  
Aref Moradkhani Roshandeh, Zhenyu Miao, Zaki Ahmad Daniyal, Yanjun Feng and Zheng John Shen

P5505 *Hybrid Algorithm for Fault Locating in Looped Microgrids*  
Siavash Beheshtaein, Mehdi Savaghebi, Juan Carlos Vasquez and Josep Guerrero

Wednesday, September 21, 8:30AM-10:10AM

Photovoltaic Converters II, Chair: Nathan Weise, Jaeho Choi, Room: 203AB 137

8:30AM *A 50kW High Power Density Paralleled-five-level PV Converter based on SiC T-type MOSFET Modules*  
Yanjun Shi, Yuxiang Shi, Lu Wang, Ren Xie and Hui Li

8:55AM *PV Array Voltage Range Extension for Photovoltaic Inverters Using a Mini-Boost*  
Emanuel Serban, Francisco Paz and Ordonez Martin

9:20AM *Submodule Integrated Boost DC-DC Converters with No External Input Capacitor or Input Inductor for Low Power Photovoltaic Applications*  
Jen-Hung Huang, Brad Lehman and Ting Qian

9:45AM *Effective Control Approach for Multi-PVs Based Resonant Converter through Cross-switched Structure*  
Ali Elrayyah, Amr Ibrahem and Yilmaz Sozer

Converter Applications for Alternative Energy Systems, Chair: Andrew Hintz, Shaojun Xie, Room: 203C 138

8:30AM *Control Scheme for the Wide Operation Range of Induction Generator with a Vienna Rectifier in Wind Turbine Systems*  
Jin-Hyuk Park, June-Seok Lee and Kyo-Beum Lee

8:55AM *GaN Based High Gain Non-Isolated DC-DC Stage of Microinverter with Extended-Duty-Ratio Boost*  
Jinia Roy and Raja Ayyanar

9:20AM *High-Efficiency Three-Level SEPIC for Grid-Tied PV Systems*  
Min-Kwon Yang, Seung-Jae Lee, Jun Heo and Woo-Young Choi

9:45AM *A Novel Zero-voltage-switched Multi-resonant DC-DC Converter*  
Ling Gu and Ke Jin

Modeling, Analysis, and Control of Grid-Connected Converters I, Chair: fred wang, Paolo Mattavelli, Room: 202D 139

8:30AM *Seamless Transfer Strategy Considering Power Balance in Parallel Operation*  
Chee Seung-Jun, Lee Younggi, Son Young-Kwang, Sul Seung-Ki, Lim Changjin and Huh Sungjae

8:55AM *Robust Control for Parallel Operated L-Inverters with Uncertainty and Disturbance Estimator*  
Yeqin Wang, Qing-Chang Zhong and Beibei Ren

9:20AM *Active and Reactive Power Operational Region for Grid-Interactive Cascaded H-Bridge Multilevel Converters*  
Jacob Lamb and Mirafzal Behrooz

9:45AM *Harmonic Stability Analysis and Controller Parameter Design of Three-Phase Inverter-Based Multi-Bus Ac Systems Based on Sequence Impedances*  
Wenchao Cao, Yiwei Ma and Fred Wang

Utility Applications II, Chair: Deepak Divan, Alireza Nami, Room: 202A 140

8:30AM *Full-ZVS Modulation for All-SiC ISOP-Type Isolated Front End (IFE) Solid-State Transformer*  
Jonas E. Huber, Daniel Rothmund, Li Wang and Johann W. Kolar

8:55AM *Stability issues in reverse power flow limitation in a Smart Transformer-fed distribution grid*  
Giovanni De Carne, Giampaolo Buticchi and Marco Liserre

9:20AM *Smart Transformer-Based Hybrid Grid Loads Support in Partial Disconnection of MV/HV Power System*  
Chandan Kumar, Zhixiang Zou and Liserre Marco

9:45AM *Soft-Switching Solid State Transformer (S4T)*  
Hao Chen and Deepak Divan

DC Microgrids I, Chair: Giovanna Oriti, Babak Parkhideh, Room: 203DE 140

8:30AM *Hierarchical Coordination of a Hybrid AC/DC SmartGrid with Central/Distributed Energy Storage*  
Pablo Arboleya, Cristina Gonzalez-Moran, Pablo Garcia, Jorge Garcia and Bassam Mohamed

8:55AM *Dynamic Optimal Power Flow for DC Microgrids with Distributed Battery Energy Storage Systems*  
Thomas Morstyn, Branislav Hredzak and Vassilios Agelidis

9:20AM *DC Electric Springs with Modified Droop Control for Storage Reduction in DC Microgrids*  
Ming Hao Wang, Shuo Yan, Siew Chong Tan and Shu Yuen Ron Hui

9:45AM *Optimal Droop Surface Control of Dc Microgrids Based on Battery State of Charge*  
Arthur Jones and Wayne Weaver

Transportation Electrification I, Chair: Bulent Sarlioglu, Tim Burress, Room: 102D 141

8:30AM *A Modified Z-source Converter based Single Phase PV/Grid Inter-connected DC Charging Converter for Future Transportation Electrification*  
Siddhartha A. Singh, Giampaolo Carli, Najath A. Azeez and Sheldon S. Williamson

8:55AM *Comprehensive design comparison of using different order harmonics as the power carrier in wireless power transfer for PHEV and EV Wireless Charging*  
Hulong Zeng and Fang Z. Peng

9:20AM *A New Inductive Wireless Power Transfer Topology Using Current-Fed Half-Bridge CLC Transmitter LC Receiver Configuration*  
Akshay Rathore and Suvendu Samanta

9:45AM *Reduction on Radiation Noise Level for Inductive Power Transfer Systems with Spread Spectrum focusing on Combined Impedance of Coils and Capacitors*  
Kent Inoue, Keisuke Kusaka and Jun-ichi Itoh

Modeling and Control of DC-DC Converters II, Chair: Reza Sabzehgar, Liuchen Chang, Room: 102C 142

8:30AM *A New High-Frequency Simulation Model for Multi-Winding Transformers used in Switched-Mode Power Supplies*  
Ripunjoy Phukan, Lakshmi Ravi, Amirhossein Shahirinia and Rangarajan Tallam

8:55AM *Multi-Phase Sliding Mode Control for Chattering Suppression in a DC-DC Converter*  
Woonki Na, Pengyuan Chen, Harkamal Singh and Jonghoon Kim

9:20AM *Gradient-reference-current Control of Tri-state Buck Converter to Improve Dynamic Response over Wide Load Range*  
Shuhan Liao, Xiaoming Zha, Fei Liu, Wenjun Liu and Kun Feng

9:45AM *A Control Strategy for Paralleled Bi-Directional DC-DC Converters Used in Energy Storage Systems*  
Zhenya Zhang, Zhao Zhang, Shaojun Xie and Chen Yang

Modulation Techniques II, Chair: Madhu Sudhan Chinthavali, Sufei Li, Room: 102E 143

8:30AM *Steady-State Analysis of the Phase Shift Modulated LLC Resonant Converter*  
Wei Liu, Binbin Wang, Wenxi Yao, Zhengyu Lu and Xiaoyi Xu

8:55AM *Practical Implementation of Global Synchronous Pulse Width Modulation with Time Delay Compensation and Distributed Calculation Capabilities*  
Tao Xu, Feng Gao and Liwei Zhou

9:20AM *Research on Zero-Sequence Circulating Currents in Parallel Three-Level Grid-Tied Photovoltaic inverters*  
Yang Li, Xu Yang, Wenjie Chen and Zhang Feng

9:45AM *Modified Pulse Energy Modulation Technique of a Three-Switch Buck-Boost Inverter*  
Shuang Xu, Riming Shao, Liuchen Chang and Shuying Yang

Modeling, Control and Stability of Modular Multilevel Converters, Chair: Rik De Doncker, Pragasen Pillay, Room: 202E 143

8:30AM *MMC-HVDC: Simulation and Control Strategy*  
Suman Debnath and Madhusudhan Chinthavali

8:55AM *Hybrid Railway Power Conditioner Based on Half-Bridge Modular Multilevel Converter*  
Li Liu and NingYi Dai

9:20AM *A PWM Method Reducing Harmonics of Two Interleaved Converters*  
Jaejin Han, Younggi Lee and Seung-Ki Sul

9:45AM *DC Impedance Modeling and Stability Analysis of Modular Multilevel Converter for MVDC Application*  
Ran Mo, Qing Ye and Hui Li

Reluctance Machines II, Chair: Babak Fahimi, Sufei Li, Room: 102B 144

8:30AM *Segmented Rotor Design of Concentrated Wound Switched Reluctance Motor (SRM) for Torque Ripple Minimization*  
Md Ashfanoor Kabir and Iqbal Husain

8:55AM *Extending the Speed Range of A Switched Reluctance Motor using a Fast Demagnetizing Technique*  
Mohamad Abd Elmutalab, Elrayyah Ali, Tausif Husain and Yilmaz Sozer

9:20AM *Development and Analysis of U-core Switched Reluctance Machine*  
Rasmus Jaeger, Simon Staal Nielsen, Kristian Kongerslev and Peter Omand Rasmussen

9:45AM *Torque Ripple and Acoustic Noise of Current Modulations of a Pseudo-Sinusoidal Switched Reluctance Motor*  
Qingqing Ma, Lanhua Zhang, Xiaonan Zhao, Xuesen Cui and Jih-Sheng Lai

PM Machines I, Chair: Ayman El-Refaie, Ali Bazzi, Room: 101A 145

8:30AM *Proposal of Electrically Reversal Magnetic Pole Type Variable Magnetic Flux PM Motor*  
Masahiro Aoyama, Kazukiyo Nakajima and Toshihiko Noguchi

8:55AM *Torque and Core Loss Characterization of a Variable-Flux Permanent-Magnet Machine*  
Chirag Desai and Pragasen Pillay

9:20AM *Examination to Enhance Efficiency of V-shaped IPMSM Using Concentrated Winding Structure at High Speed and High Torque Area*  
Ayato Nihonyanagi, Takemoto Takemoto, Satoshi Ogasawara, Naohiko Aoki and Kwansu Lee

9:45AM *Advanced High Torque Density Non-overlapping Winding PM Vernier Machines*  
Tianjie Zou, Dawei Li, Ronghai Qu, Jian Li and Dong Jiang

Drive/Utility Interface, Chair: Wenping Cao, Shih-Chin Yang, Room: 101B 145

8:30AM *Synchronous Switching of Non-Line-Start Permanent Magnet Synchronous Machines between Inverter and Grid Drives*  
Ronggang Ni, Dianguo Xu, Frede Blaabjerg, Gaolin Wang, Binbin Li and Kaiyuan Lu

8:55AM *Instability Detection and Protection Scheme for Efficiency Optimized V/f Driven Synchronous Reluctance Motors (SynRM)*  
Sara Ahmed, Gholamreza Jalali, Zach Pan and Hongrae Kim

9:20AM *Power-Quality-Oriented Optimization in Multiple Three-Phase Adjustable Speed Drives*  
Yongheng Yang, Pooya Davari, Frede Blaabjerg and Firuz Zare

9:45AM *A Four-Quadrant Permanent Magnet Synchronous Machine Drive with a Tiny DC Link Capacitor*  
Mahima Gupta and Giri Venkataramanan

PM and IPM Motor Drives II, Chair: Omer Onar, Rakib Islam, Room: 101CD 146

8:30AM *Effect of Position Sensor error on the Performance of IPMSM drives*  
Ramakrishnan Raja, Tomy Sebastian, Mengqi Wang, Mohammad Islam and Abraham Gebregergis

8:55AM *Signal-Injection-Aided Position and Speed Estimation for PMSM Drives with Low-Resolution Position Sensors*  
Giulio De Donato, Giacomo Scelba, Mario Pulvirenti, Giuseppe Scarcella and Fabio Giulii Capponi

9:20AM *Integrated Switch Current Sensor for Shortcircuit Protection and Current Control of 1.7-kV SiC MOSFET Modules*  
Jun Wang, Zhiyu Shen, Rolando Burgos and Dushan Boroyevich

9:45AM *Current Reconstruction Method for PMSM Drive System with a DC Link Shunt Resistor*  
Han-Beom Yeom, Hyun-Keun Ku and Jang-Mok Kim

Modeling of WBG Devices and Modules, Chair: Enrico Santi, Robert Pilawa-Podgurski, Room: 202C 147

8:30AM *PSpice Modeling Platform for SiC Power MOSFET Modules with Extensive Experimental Validation*  
Lorenzo Ceccarelli, Muhammad Nawaz and Francesco Iannuzzo

8:55AM *Development of Simulink-Based SiC MOSFET Modeling Platform for Series Connected Devices*  
Georgios Tsolaridis, Kalle Ilves, Paula Diaz Reigoza, Muhammad Nawaz and Francesco Iannuzzo

9:20AM *An Accurate Subcircuit Model of SiC Half Bridge Module for Switching Loss Optimization*  
Pengfei Tu, Shan Yin, Peng Wang, King Jet Tseng, Chen Qi, Xiaolei Hu, Michael Adam Zagrodnik and Rejeki Simanjorang

9:45AM *Spatial Electro-Thermal Modeling and Simulation of Power Electronic Modules*  
Christoph van der Broeck, Lukas Ruppert and Rik De Doncker

Gate Drive Techniques II, Chair: Daniel Costinett, Pradeep S. Shenoy, Room: 102A 148

8:30AM *Automatic Optimization of IGBT Gate Driving Waveform Using Simulated Annealing for Programmable Gate Driver IC*  
Koutarou Miyazaki, Makoto Takamiya and Takayasu Sakurai

8:55AM *Active dv/dt Control of 600V GaN Transistors*  
Bingyao Sun, Rolando Burgos, Xuning Zhang and Dushan Boroyevich

9:20AM *Commutation Strategies for Single-Chip Dual-Gate Bidirectional IGBTs in Matrix Converters*  
Daming Wang, Sai Tang, Jun Wang, Zhengbin Xiong, Shanglin Mo, Xin Yin, Zhikang Shuai and Z. John Shen

9:45AM *Two Comparison-Alternative High Temperature PCB-Embedded Transformer Designs for a 2 W Gate Driver Power Supply*  
Bingyao Sun, Remi Perrin, Cyril Buttay, Bruno Allard, Nicolas Quentin, Rolando Burgos, Dushan Boroyevich and Marwan Ali

Wireless Power Transfer III, Chair: Tsorng-Juu Liang, Khurram Afridi, Room: 202B 149

8:30AM *Performance Analysis of Magnetic Power Pads for Inductive Power Transfer Systems with Ferrite Structure Variation*  
Minkook Kim, Jongeun Byeon, Jae-Woo Lee and Byoung Kuk Lee

8:55AM *Analysis of Mutually Decoupled Primary Coils for IPT Systems for EV Charging*  
Seho Kim, Abiezer Tejeda, Grant Anthony Covic and John Talbot Boys

9:20AM *Dynamic Matching System for Radio-Frequency Plasma Generation*  
Anas Al Bastami, Alexander Jurkov, Parker Gould, Mitchell Hsing, Martin Schmidt and David Perreault

9:45AM *A Loosely Coupled Capacitive Power Transfer System with LC Compensation Circuit Topology*  
Hua Zhang, Fei Lu, Heath Hofmann, Weiguo Liu and Chris Mi

Wednesday, September 21, 10:30AM-12:10PM

Control for Photovoltaic Applications, Chair: Martin Ordonez, Dezso Sera, Room: 203AB 149

10:30AM *A Variable Step-Size MPPT for Sensorless Current Model Predictive Control for Photovoltaic Systems*  
Morcos Metry, Mohammad B. Shadmand, Robert S. Balog and Haitham Abu-Rub

10:55AM *Study on the Unbalanced Current Injection Capability of Grid-Connected Photovoltaic Neutral-Point-Clamped Inverter*  
Hossein Dehghani Tafti, Ali Iftekhar Maswood, Karthik Kandasamy, Ziyou Lim, Gabriel Ooi Heo Peng, Georgios Konstantinou and Josep Pou

11:20AM *Adaptive Dc Link Voltage Control Scheme for Single Phase Inverters with Dynamic Power Decoupling*  
Yinglai Xia and Raja Ayyanar

11:45AM *ZVS Analysis and Power Flow Control for Three Limb Transformer Enabled SiC Mosfet Based Three Port DAB Integrating PV and Energy Storage(ES)*  
Ritwik Chattopadhyay and Subhashish Bhattacharya

Photovoltaic Characterization and Modeling, Chair: Tirthajyoti Sarkar, Ahmed Elasser, Room: 203C 150

10:30AM *A Rapid I-V Curve Generation for PV Model-based Solar Array Simulators*  
Young-Tae Seo, Jun-Young Park and Sung-Jin Choi

10:55AM *Photovoltaic Panel Simulation Based on Individual Cell Condition*  
Eduardo Abdon Sarquis Filho, Fabiano Fragoso Costa, Andre Pires Nobrega Tahim and Antonio Cezar de Castro Lima

11:20AM *Development and implementation of a PV performance monitoring system based on inverter measurements*  
Sergiu Spataru, Anamaria Gavriluta, Lars Maaloe, Dezso Sera and Ole Winther

11:45AM *Characterization of Silicon Based Photovoltaic Cells Using Broadband Impedance Spectroscopy*  
Olufemi Olayiwola and Paul Barendse

Utility Applications III, Chair: Srdjan Lukic, Deepak Divan, Room: 202A 151

10:30AM *DC Solid State Transformer Based on Input-Series-Output-Parallel Dual-Active-Bridge for MVDC Power Distribution*  
Biao Zhao, Qiang Song, Jianguo Li and Wenhua Liu

10:55AM *Six-Leg Single-Phase to Three-Phase Converter*  
Nayara Brandao de Freitas, Cursino Brandao Jacobina, Ayslan Caisson Noroes Maia and Alexandre Cunha Oliveira

11:20AM *Flexible Transformers for Distribution Grid Control*  
Hao Chen, Prasad Kandula, Anish Prasai, Joe Schatz and Deepak Divan

11:45AM *Comparative Analysis of Modular Multiport Power Electronic Transformer Topologies*  
Mario Lopez, Fernando Briz, Mariam Saeed, Manuel Arias and Alberto Rodriguez

Modeling, Analysis, and Control of Grid-Connected Converters II, Chair: Frede Blaabjerg, Rajendra Prasad Kandula, Room: 202D 152

10:30AM *Advanced Control of a High Power Converter Connected to Weak Grids*  
Shahparasti Mahdi, Catalan Pedro, Luna Alvaro, Candela Jose Ignacio and Rodriguez Pedro

10:55AM *A Power Density Optimization Method for a Power Pulsation Decoupling Buffer in Single-Phase DC-AC Converters*  
Shibin Qin and Robert Pilawa-Podgurski

11:20AM *Control Design in $$-Synthesis Framework for Grid-Connected Inverters with Higher Order Filters*  
Nima Amouzegar Ashtiani, Mohsen Azizi and Sayed Ali Khajehoddin

11:45AM *Sensorless Current Model Predictive Control for Maximum Power Point Tracking of Single-Phase subMultilevel Inverter for Photovoltaic Systems*  
Morcos Metry, Sertac Bayhan, Mohammad B. Shadmand, Robert S. Balog and Haitham Abu-Rub

DC Microgrids II, Chair: Josep M. Guerrero, Ali Davoudi, Room: 203DE 152

10:30AM *An Adaptive Power Distributed Control Method to Ensure Proportional Load Power Sharing in DC Microgrid Considering Equivalent Line Impedances*  
Duy-Hung Dam and Hong-Hee Lee

10:55AM *The Performance of Polytopic Models in Smart DC Microgrids*  
Airan Frances, Rafael Asensi, Oscar Garcia, Roberto Prieto and Javier Uceda

11:20AM *Study on DC Arc Faults in Ring-Bus DC Microgrids with Constant Power Loads*  
Xiu Yao

11:45AM *Stability Analysis and Improvement of a Dual Active Bridge (DAB) Converter Enabled DC Microgrid based on a Reduced-order Low Frequency Model*  
Qing Ye, Ran Mo and Hui Li

Datacenters and Telecommunication Applications, Chair: Philip Krein, Johan Enslin, Room: 102E 153

10:30AM *Soft-Switching Operation of Edge-Resonant Output-Inductor-Less Full-Bridge Converter*  
Kazuhide Domoto, Yoichi Ishizuka, Seiya Abe and Tamotsu Ninomiya

10:55AM *High Efficiency Two-Stage 48V VRM with PCB Winding Matrix Transformer*  
Mohamed Ahmed, Chao Fei, Fred C. Lee and Qiang Li

11:20AM *Hierarchical Protection Architecture for 380V DC Data Center Application*  
Kai Tan, Xiaoqing Song, Chang Peng, Pengkun Liu and Alex Huang

11:45AM *Device Loss Comparison of GaN Device Based LLC, Dual Active Bridge and Phase Shift Quasi Switched Capacitor Circuit*  
Boxue Hu, Xuan Zhang, Lixing Fu, He Li, Yousef M. Abdullah, Yafeng Wang, Lurao Liu and Jin Wang

Transportation Electrification II, Chair: Sinisa Jurkovic, Bruno Lequesne, Room: 102D 154

10:30AM *Loss Optimizing Control of a Multiphase Interleaving DC-DC Converter for Use in a Hybrid Electric Vehicle Drivetrain*  
Rashidreza Karimi, Dennis Kaczorowski, Alexander Zlotnik and Mertens Axel

10:55AM *Traction Inverter Evaluation Method Based on Driving Cycles for Electric and Hybrid Electric Vehicles*  
Fan Xu and Lihua Chen

11:20AM *Model Predictive Control based Field-weakening Strategy for Traction EV used Induction Motor*  
Jianyong Su, Rui Gao and Iqbal Husain

11:45AM *Design Optimization and Development of Electric Traction Machines for Cadillac CT6 PHEV*  
Sinisa Jurkovic, Khwaja Rahman and Peter Savagian

PFC Rectifiers, Chair: Ned Mohan, Alessandro Costabeber, Room: 202E 155

10:30AM *Active Virtual Ground - Bridgeless PFC Topology*  
Carl Ngai-Man Ho, River Tin-Ho Li and Ken King-Man Siu

10:55AM *A 500 kHz, 3 kW power factor correction circuit with low loss auxiliary ZVT circuit*  
Siddharth Kulasekaran and Raja Ayyanar

11:20AM *A Two-Switch Buck-Boost PFC Rectifier With Automatic AC Power Decoupling Capability*  
Wenlong Qi, Sinan Li, Siew Chong Tan and Shu Yuen Ron Hui

11:45AM *High Efficiency Bridgeless Power Factor Correction Buck Converter for High Frequency AC Systems*  
Zhe Yang, Sitthisak Kiratipongvoot and Chi Kwan Lee

Modeling and Control of Multilevel converters, Chair: Mengqi Wang, Marcello Pucci, Room: 202B 156

10:30AM *An Improved Proportional Pulse Compensation Strategy for DC Voltage Balance of Cascaded H-Bridge Rectifier*  
Xiang Li, Jian Wang, Xiaojie You and Kun Wang

10:55AM *Cost effective Capacitor Voltage Balancing Control for Five-level Grid-tied Inverters*  
Mingchen Gu, Li Zhang, Kai Sun, Yan Xing and Peng Xu

11:20AM *A Single Phase T-type Inverter Operating in Boundary Conduction Mode*  
Zhen Zhang, Junming Zhang and Xinke Wu

11:45AM *Three-Phase Four-Wire AC-DC-AC Multilevel Topologies Obtained from an Interconnection of Three-leg Converters*  
Ayslan Caisson Noroes Maia, Cursino Brandao Jacobina, Nayara Brandao de Freitas, Antonio de Paula Dias Queiroz and Edison Roberto Cabral da Silva

Modeling and Control of Resonant Converters, Chair: Rolando Burgos, Marko Hinkkanen, Room: 102C 156

10:30AM *Extreme Start-Up Response of LLC Converters Using Average Geometric Control*  
Mehdi Mohammadi and Martin Ordonez

10:55AM *Optimized Resonant Pulsed Power Supplies with Deadbeat - Repetitive Regulation*  
Chao Ji, Jon Clare and Pericle Zanchetta

11:20AM *Control and Operation of Medium-voltage High-power Bi-directional Resonant DC-DC Converters in Shipboard DC Distribution Systems*  
Dong Dong, Luis Garces, Mohammed Agamy, Yan Pan, Xinhui Wu, He Xu, Hongwu She, Xiaohong Li and Jian Dai

11:45AM *Inductance Cancellation in RF Resonant Power Converters*  
Max Praglin, Luke Raymond and Juan Rivas

Electric Machines for Automotive Applications I, Chair: Thomas Jahns, Sinisa Jurkovic, Room: 102B 157

10:30AM *Retrospective of Electric Machines for EV and HEV Traction Applications at General Motors*  
Khwaja Rahman, Sinisa Jurkovic, Peter Savagian, Nitinkumar Patel and Robert Dawsey

10:55AM *High-Performance Partitioned-Stator Switched Flux Memory Machines with Hybrid Magnets on External Stator for Automotive Traction Applications*  
Hui Yang, Z. Q. Zhu, Heyun Lin, Shuhua Fang and Yunkai Huang

11:20AM *Test Results for a High Temperature Non-Permanent Magnet Traction Motor*  
Tsarafidy Raminosoa, Ayman El-Refaie, David Torrey, Kevin Grace, Di Pan, Stefan Grubic, Karthik Bodla and Kum-Kang Huh

11:45AM *Vehicular Suspension and Propulsion Using Double Sided Linear Induction Machines*  
Tom Cox, Fred Eastham and Matt Dickinson

PM Machines II, Chair: Siavash Pakdelian, Nicola Bianchi, Room: 101A 158

10:30AM *Experimental Verification of Rotor Demagnetization in a Fractional-Slot Concentrated-Winding PM Synchronous Machine under Drive Fault Conditions*  
Gilsu Choi, Yichao Zhang and Thomas Jahns

10:55AM *Influence of Stator Configuration on High Frequency Signal Injection Based Permanent Magnet Temperature Estimation in PMSMs*  
Daniel Fernandez, David Reigosa, Devraj Dutt, Zi-Qiang Zhu and Fernando Briz

11:20AM *Analysis and Design Guidelines to Mitigate Demagnetization Vulnerability in PM Synchronous Machines*  
Gilsu Choi and Thomas Jahns

11:45AM *The Nature of the Torque Ripple in Fractional-slot Synchronous PMAREL Machines*  
Nicola Bianchi, Alessandro Castagnini, Giulio Secondo and Pietro Savio Termini

Multilevel Motor Drives, Chair: Luca Zarri, Yi Deng, Room: 101B 158

10:30AM *A Fault-Tolerant T-Type Multilevel Inverter Topology with Soft-Switching Capability Based on Si and SiC Hybrid Phase Legs*  
Jiangbiao He, Nathan Weise, Ramin Katebi, Lixiang Wei and Nabeel Demerdash

10:55AM *An On-Line Diagnostic Method for Open-Circuit Switch Faults in NPC Multilevel Converters*  
Jiangbiao He and Nabeel Demerdash

11:20AM *Analysis of Neutral Point Deviation in 3-level NPC Converter under Unbalanced 3-phase AC Grid*  
Kyungsub Jung and Yongsug Suh

11:45AM *A Modulation Technique of Neutral Point Clamped Converters with Common-Mode Voltage Reduction and Neutral-Point Potential Balance*  
Meng-Jiang Tsai, Hsin-Chih Chen, Po-Tai Cheng, Meng-Ru Tsai and Yao-Bang Wang

PM and IPM Motor Drives III, Chair: Takahiro Suzuki, Nicola Bianchi, Room: 101CD 159

10:30AM *Magnet Temperature Effects on the Useful Properties of Variable Flux PM Synchronous Machines and a Mitigating Method for Magnetization Changes*  
Brent Gagas, Kensuke Sasaki, Apoorva Athavale, Takashi Kato and Robert Lorenz

10:55AM *Nonintrusive Online Rotor Permanent Magnet Temperature Tracking for Permanent Magnet Synchronous Machine Based on Third Harmonic Voltage*  
Hanlin Zhan and Z.Q. Zhu

11:20AM *Permanent Magnet Temperature Estimation in PMSM Using Low Cost Hall Effect Sensors*  
Daniel Fernandez, Doosoo Hyun, Yonghyun Park, David Reigosa, Sang Bin Lee, Dong Myung Lee and Fernando Briz

11:45AM *Analysis and Suppression of Zero Sequence Circulating Current in Open Winding Permanent Magnet Synchronous Machine Drives with Common DC Bus*  
Hanlin Zhan, Z.Q. Zhu and Milijana Odavic

Wide Bandgap Applications: SiC, Chair: Ruxi Wang, Jerry Hudgins, Room: 202C 160

10:30AM *A Compact 100-A, 850-V, Silicon Carbide Solid-State DC Circuit Breaker*  
Damian Urciuoli, Oladimeji Ibitayo, Gail Koebke, Gregory Ovrebo and Ronald Green

10:55AM *Matrix Converter with Sinusoidal Input-Output Filter and Filter Downsizing Using SiC Devices*  
Yasunori Furukawa, Takeshi Kinomae, Hidenori Hara, Masato Higuchi, Ryoji Tomonaga, Kohei Shirabe and Tsuneo Kume

11:20AM *H-Bridge Building Block with SiC Power MOSFETs for Pulsed Power Application*  
Ruxi Wang, Juan Sabate, Fengfeng Tao, Cong Li, Xiaohu Liu and Fei Xu

11:45AM *Three-phase active front-end rectifier efficiency improvement with silicon carbide power semiconductor devices*  
Mao Saijun, Wu Tao, Lu Xi, Popovic Jelena and Ferreira Jan Abraham

LED Drivers, Chair: Huai Wang, David Perreault, Room: 102A 161

10:30AM *Precise and Full-Range Dimming Control for An Off-Line Single-Inductor-Multiple-Output LED Driver*  
Sinan Li, Yue Guo, Ting Leung Albert Lee, Siew Chong Tan and Shu Yuen Ron Hui

10:55AM *Design and Implementation of a Retrofit LED Lamp for AC Mains and Ballasts*  
Tsorng-Juu Liang, Huan-Hao Chang, Kai-Hui Chen and Li-An Hsu

11:20AM *A Current Compensator for Mitigating the Influence of Long Cable Inductance between the LED Driver and the Light Source*  
Rui Zhou, Ryan Shun-Cheung Yeung, Henry Shu-Hung Chung, John Yau-Chung Chan and Norman Chung-fai Tse

11:45AM *Investigation into the Use of Single Inductor for Driving Multiple Series-Connected LED Channels*  
Xiaoqing Zhan, Henry Shu-Hung Chung and Ruihong Zhang

Wednesday, September 21, 1:30PM-3:10PM

Modeling and Control of Alternative Energy Applications, Chair: Eduard Muljadi, Akshay Kumar Rathore, Room: 203C 161

1:30PM *Using Markov Switching Model for Solar Irradiance Forecasting in Remote Microgrids*  
Ayush Shakya, Semhar Michael, Christopher Saunders, Douglas Armstrong, Prakash Pandey, Santosh Chalise and Reinaldo Tonkoski

1:55PM *Determining Maximum MPP-Tracking Sampling Frequency for Input-Voltage-Controlled PV-Interfacing Converter*  
Jyri Kivimaki, Moshe Sitbon, Sergei Kolesnik, Alon Kuperman and Teuvo Suntio

2:20PM *Real-time Emulation of a Pressure Retarded Osmosis Power Generation System*  
Sudharshan Kaarthik, Jonathan Maisonneuve and Pragasen Pillay

2:45PM *Efficient FCTV Provision considering DWT and DWPT-based Noise Suppression for Overcoming the Noise-Induced Voltage Loss in PEM Fuel Cell*  
Jonghoon Kim, Woonki Na and Yongsug Tak

Utility Applications IV, Chair: Fariba Fateh, Yipeng Song, Room: 202A 162

1:30PM *Field Test Results for a 12.47 kV 3-Phase 1 MVA Power Router*  
Rajendra Prasad Kandula, Hao Chen, Anish Prasai, Frank Lambert, Joe Schatz, Thomas Powell, Timothy Heidel, Colin Schauder and Deepak Divan

1:55PM *DC Capacitor Voltage Balancing Control for Delta-Connected Cascaded H-Bridge STATCOM Considering the Unbalanced Grid and Load Conditions*  
Jae-Jung Jung, Joon-Hee Lee, Seung-Ki Sul, Gum Tae Son and Young-Ho Chung

2:20PM *Advanced Grid Simulator for Multi-Megawatt Power Converter Testing and Certification*  
Przemyslaw Koralewicz, Vahan Gevorgian, Pieder Joerg, Wim van der Merwe and Robb Wallen

2:45PM *Experimental Verification of Capacitance Reduction in MMC-Based STATCOM*  
Takanori Isobe, Long Zhang, Ryuji Iijima, Hiroshi Tadano, Yasuhiko Kawanami and Katsushi Terazono

Modeling, Analysis, and Control of Grid-Connected Converters III, Chair: Ali Davoudi, Edison da Silva, Room: 202D 163

1:30PM *A Comparative Study of Methods for Estimating Virtual Flux at the Point of Common Coupling in Grid Connected Voltage Source Converters With LCL Filter*  
Nurul Fazlin Roslan, Jon Are Suul, Alvaro Luna, Joan Rocabert, Ignacio Candela and Pedro Rodriguez

1:55PM *A Novel Model Predictive Sliding Mode Control for AC/DC Converters with Output Voltage and Load Resistance Variations*  
Tingting He, Li Li, Jianguo Zhu and Zheng Linfeng

2:20PM *A Novel Virtual Synchronous Generator Control Strategy Based on Improved Swing Equation Emulating and Power Decoupling Method*  
Mingxuan Li, Yue Wang, Ningyi Xu, Yonghui Liu, Wenti Wang, Hao Wang and Wanjun Lei

2:45PM *Virtual Impedance-Based Active Damping for LCL Resonance in Grid-Connected Voltage Source Inverters with Grid Current Feedback*  
Teng Liu, Zeng Liu, Jinjun Liu and Zipeng Liu

WBG in Traction Application, Chair: Burak Ozpineci, Anand Sathyan, Room: 102D 164

1:30PM *Component Design and Implementation of a 60 kW Full SiC Traction Inverter with Boost Converter*  
Arvid Merkert, Jan-Kaspar Mueller and Axel Mertens

1:55PM *Design Methodology for a Planarized High Power Density EV/HEV Traction Drive using SiC Power Modules*  
Dhrubo Rahman, Adam Morgan, Yang Xu, Rui Gao, Wensong Yu, Douglas C. Hopkins and Iqbal Husain

2:20PM *A SiC-Based High-Performance Medium-Voltage Fast Charger for Plug-in Electric Vehicles*  
Srdjan Srdic, Xinyu Liang, Chi Zhang, Wensong Yu and Srdjan Lukic

2:45PM *An Integrated Onboard Charger and Accessory Power Converter for Traction Drive Systems with a Boost Converter*  
Gui-Jia Su and Lixin Tang

Single Phase Rectifiers, Chair: Adam Skorek, Euzeli Santos Jr., Room: 202E 164

1:30PM *Current-stress Reduction of the Neutral Inductor in a Rectifier with Two Outputs*  
Wen-Long Ming and Qing-Chang Zhong

1:55PM *Single-stage AC/DC Dual Inductor BCM Current-Fed Push-Pull for HB-LED lighting applications*  
Ignacio Castro, Kevin Martin, Manuel Arias, Diego G. Lamar, Marta M. Hernando and Javier Sebastian

2:20PM *Asymmetric Single-Phase Current Source Rectifiers*  
Louelson Costa, Montie Vitorino, Mauricio Correa, Darlan Fernandes and Oliveira Marcus

2:45PM *A Bridgeless Controlled Rectifier for Single Split-Phase Systems*  
Nustenil S de M. L. Marinus, Cursino B Jacobina, Euzeli C dos Santos Jr., Nady Rocha and Nayara B. Freitas

Multilevel Converters, Chair: NingYi Dai, Marcello Pucci, Room: 202B 165

1:30PM *Modulation Method for Single-Phase Six-Switch Five-Level ANPC Inverter*  
Lei Kou, Hongliang Wang, Yan-fei Liu, Paresh C. Sen and Yan Zhang

1:55PM *Modified SVPWM to Eliminate Common-Mode Voltages for Five-Level ANPC Inverters*  
Quoc Anh Le and Dong-Choon Lee

2:20PM *THD and Efficiency improvement in Multi-Level Inverters through an Open End Winding Configuration*  
Salvatore De Caro, Salvatore Foti, Tommaso Scimone, Antonio Testa, Mario Cacciato, Giuseppe Scarcella and Giacomo Scelba

2:45PM *A Source-Type Harmonic Energy Unbalance Suppression Method Based on Carrier Frequency Optimization for Cascaded Multilevel APF*  
Zezhou Yang, Shangshen Li, Xiaoming Zha, Jianjun Sun and Wang Yi

DC-DC Converters II, Chair: Yan-Fei Liu, Lixiang Wei, Room: 102C 166

1:30PM *Small-Signal Model and Control of the Interleaved Two-Phase Coupled-Inductor Boost Converter*  
Brendan C. Barry, John G. Hayes, Marek S. Rylko, Robert Stala, Adam Penczek, Andrzej Mondzik and Robert T. Ryan

1:55PM *A Robust Design Framework for Stable Digital Peak Current-Mode Control Under Uniform Sampling*  
Amit Singha, Santanu Kapat and Jayanta Pal

2:20PM *Modeling and Decoupled Control of a Non-isolated High Step-up/down Bidirectional DC-DC Converter*  
Haixu Shi, Xi Xiao, Hongfei Wu and Kai Sun

2:45PM *Non-Isolated High-Gain Three-Port Converter for Hybrid Storage Systems*  
Jorge Garcia, Ramy Georgious, Pablo Garcia and Angel Navarro-Rodriguez

Reliability, Diagnostic and Faults Analysis in Power Converters I , Chair: Jiangchao Qin, Martin Ordonez, Room: 102E 167

1:30PM *System-level Reliability Assessment of Power Stage in Fuel Cell Application*  
Dao Zhou, Huai Wang, Frede Blaabjerg, Soeren Kundsen Kaer and Daniel Blom Hansen

1:55PM *A Novel Online ESR and C Identification Method for Output Capacitor of Flyback Converter*  
Hui Li, Kai Yao, Xufeng Zhou, Fei Yang and Junfang Zhang

2:20PM *Fault Ride-Through Capability for Grid-Supporting Inverters*  
Prasanna Piya, Masoud Karimi-Ghartemani and Ali S. Khajehoddin

2:45PM *Analysis of Hybrid Energy Storage Systems with DC Link Fault Ride-Through Capability*  
Ramy Georgious, Mark Sumner, Jorge Garcia and Pablo Garcia

Electric Machines for Automotive Applications II, Chair: Heath Hofmann, Jing Xue, Room: 102B 167

1:30PM *Optimisation of the Torque Quality of a Combined Phase Transverse Flux Machine for Traction Applications*  
Jamie Washington, Cristofaro Pompermaier and Glynn Atkinson

1:55PM *An Examination for Improvement of Constant Output Characteristics at High-Speed Region in a Spoke-Type IPMSM using Ferrite Permanent Magnet by Changing the Shape of Rotor Surface*  
Shoya Nagano, Masatsugu Takemoto and Satoshi Ogasawara

2:20PM *Variable Flux Permanent Magnet Synchronous Machine (VF-PMSM) Design to Meet Electric Vehicle Traction Requirements with Reduced Losses*  
Apoorva Athavale, Kensuke Sasaki, Brent Gagas, Takashi Kato and Robert Lorenz

2:45PM *Comparison of Traction Motors that Reduce or Eliminate Rare-Earth Materials*  
Ayman El-Refaie, Tsarafidy Raminosoa, Patel Reddy, Steven Galioto, Di Pan, Kevin Grace, James Alexander and Kum-Kang Huh

PM Machines III, Chair: Hamid A. Toliyat, Jie Shen, Room: 101A 168

1:30PM *Active Voltage Regulation of Partitioned Stator Switched Flux Permanent Magnet Generator Supplying Isolated Passive Load*  
Hanlin Zhan, Z.Q. Zhu and Zhongze Wu

1:55PM *Coupled and Simplified Model of the Symmetrical and Asymmetrical Triple Star Nine-Phase Interior Permanant Magnet Machines*  
Olorunfemi Ojo

2:20PM *Design and Analysis of a Novel Three-phase Flux Reversal Machine*  
Yuting Gao, Ronghai Qu, Dawei Li, Jian Li and Yongsheng Huo

2:45PM *Design, Control and Implementation of a Non-Rare-Earth Flux Switching Permanent Magnet Machine*  
Chandan Sikder, Iqbal Husain and Wen Ouyang

Drive Applications, Chair: Davide Barater, Uday Deshpande, Room: 101B 169

1:30PM *A New Normal Mode dv/dt Filter With Resistor Failure Detection Circuit*  
Mark Baumgardner and Mahesh Swamy

1:55PM *Simulation of Cable Charging Current and Its Effects on Operation of Low Power AC Drives*  
Helen Lewis-Rzeszutek, Ripunjoy Phukan, Rangarajan Tallam, Mark Solveson and Timothy Clancy

2:20PM *Systematic Modeling for a Three Phase Inverter with Motor and Long Cable using Optimization Method*  
Hui Zhao, Shuo Wang, Jianjun Min and Zhi Yongjian

2:45PM *Performance Evaluation of SiC MOSFETs with Long Power Cable and Induction Motor*  
Peizhong Yi, Puneeth Kumar Srikanta Murthy and Lixiang Wei

Sensorless Drives I, Chair: Giacomo Scelba, Ramakrishnan Raja, Room: 101CD 170

1:30PM *Design consideration of interior permanent magnet machine position sensorless drive using square-wave voltage injection*  
Shih-Chin Yang, Sheng-Ming Yang and Jing-Hui Hu

1:55PM *A Synchro-Perspective-Based High-Frequency Signal Injection Method for Position-Sensorless Vector Control of Doubly-Fed Induction Machines*  
Anuwat Srivorakul and Surapong Suwankawin

2:20PM *Enhancing Estimation Accuracy by Applying Cross-Correlation Image Tracking to Self-Sensing Including Evaluation on a Low Saliency Ratio Machine*  
Timothy Slininger, Yinghan Xu and Robert Lorenz

2:45PM *The Crowded Axis of the Frequency: Optimal Pole/Zero Allocation for a Full Speed Sensorless Synchronous Motor Drives*  
Virginia Manzolini, Mattia Morandin and Silverio Bolognani

Junction Temperature Sensing and Monitoring, Chair: Adam Skorek, Tanya Gachovska, Room: 102A 170

1:30PM *An IGBT Junction Temperature Measurement Method via Combined TSEPs For Eliminating Impact of Collector Current*  
Xiang Wang, Chong Zhu, Haoze Luo, Zhou Lu, Wuhua Li, Xiangning He, Jun Ma, Guodong Chen, Ye Tian and Enxing Yang

1:55PM *DeltaTj Control of Switching Power Devices at Thermal Boundaries via Physics-Based Loss Manipulation*  
Timothy Polom, Boru Wang and Robert Lorenz

2:20PM *Online Junction Temperature Monitoring Using Turn-Off Delay Time for Silicon Carbide Power Devices*  
Zheyu Zhang, Xuanlyu Wu, Fred Wang, Daniel Costinett, Leon Tolbert and Blalock Benjamin

2:45PM *Simple Analog Detection of Turn-off Delay Time for IGBT Junction Temperature Estimation*  
Simon Weber, Michael Schlueter, Daniel Borowski and Axel Mertens

Wide Bandgap Applications: GaN, Chair: Filippo Chimento, Jean-Luc Schanen, Room: 202C 171

1:30PM *Design of a 10 kW GaN-based High Power Density Three Phase Inverter*  
He Li, Xuan Zhang, Zhengda Zhang, Chengcheng Yao, Feng Qi, Boxue Hu, Liming Liu and Jin Wang

1:55PM *High-frequency DC-DC Converter in Electric Vehicle Based on GaN Transistors*  
Zhenjin Pang, Xiaoyong Ren, Junlin Xiang, Qianhong Chen, Xinbo Ruan and Wu Chen

2:20PM *A GaN-based Flying-Capacitor Multilevel Boost Converter for High Step-up Conversion*  
Zitao Liao, Yutian Lei and Robert Pilawa-Podgurski

2:45PM *A GaN based High Frequency Active-clamp Buck Converter for Automotive Applications*  
Chenhao Nan, Raja Ayyanar and Youhao Xi

Applications of Droop Control, Chair: Tsorng-Juu Liang, Keyue Smedley, Room: 203AB 172

1:30PM *Energy Storage Size and Fuel Consumption Reduction in a Microgrid Using Virtual Droop Control Framework*  
Ashish Solanki and Adel Nasiri

1:55PM *Seamless Black Start and Reconnection of LCL-filtered Solid State Transformer Based On Droop Control*  
Yonghwan Cho, Yongsu Han, Richard Byron Beddingfield, Jung-Ik Ha and Subhashish Bhattacharya

2:20PM *A Circulating Current Suppression Method for Parallel Connected Voltage-Source-Inverters (VSI) with Common DC and AC Buses*  
Baoze Wei, Xiaoqiang Guo, Josep M. Guerrero and Juan C. Vasquez

2:45PM *Decentralized Method for Load Sharing and Power Management in a Hybrid Single/Three-Phase Islanded Microgrid Consisting of Hybrid Source PV/Battery Units*  
Yaser Karimi, Josep M. Guerrero and Hashem Oraee

DC Microgrids III, Chair: Giovanna Oriti, Tsorng-Juu Liang, Room: 203DE 173

1:30PM *A New Secondary Control Approach for Voltage Regulation in DC Microgrids*  
Saeed Peyghami-Akhuleh, Hossein Mokhtari, Pooya Davari, Poh Chiang Loh and Frede Blaabjerg

1:55PM *CERTS Microgrids with Photovoltaic Microsources and Feeder Flow Control*  
Zhe Chen, Dinesh Pattabiraman, Robert H. Lasseter and Thomas M. Jahns

2:20PM *Combined Optimization of SSCB Snubber and Freewheeling Path for Surgeless and Quick Bus Fault Interruption In Low-Voltage DC Microgrid*  
Wenjun Liu, Xiaoqi Xiong, Hua Yang, Kun Feng, Si Zhang and Fei Liu

2:45PM *Symmetric Droop Control for Improved Hybrid AC/DC Microgrid Transient Performance*  
Philip Hart, Robert Lasseter and Thomas Jahns

Wednesday, September 21, 3:30PM-5:10PM

Wind Energy Control and Operations, Chair: Eduard Muljadi, Pedro Rodriguez, Room: 203AB 173

3:30PM *Small Scale Reluctance Synchronous Generator Wind-Turbine System with DC Transmission Linked Inverters*  
Joshua Cole Mitchell, Maarten Jan Kamper and Christoph M. Hackl

3:55PM *Short-Term Forecasting of Inertial Response from a Wind Power Plant*  
Eduard Muljadi, Vahan Gevorgian and Anderson Hoke

4:20PM *A 3.0MW Case Study of the Influence of PM Cost on Wind Turbine Cost of Energy*  
Matthew Henriksen, Bogi Bech Jensen, Nenad Mijatovic and Holboell Joachim

4:45PM *Direct Power Control of a Doubly Fed Induction Generator Wind Power System in Stand-Alone and Grid-Connected Modes with Seamless Transition*  
Sam Mahmodicherati, Malik Elbuluk and Yilmaz Sozer

Energy Harvesting Systems, Chair: Paul Barendse, Xiongfei Wang, Room: 203C 174

3:30PM *Temperature Dependence of Efficiency in Renewable Magnetohydrodynamic Power Generation Systems*  
Eva Cosoroaba and Babak Fahimi

3:55PM *Modeling, Analysis and Design of An Undersea Storage System*  
Seyyedmahdi Jafarishiadeh, Mehdi Farasat and Amir Masoud Bozorgi

4:20PM *The Joint Design of a Compressed Air and Wind Energy System for Mechanical Spillage Recovery*  
Jie Cheng and Fred Choobineh

4:45PM *Experimental Control of a Hydraulic Wind Power Transfer System under Wind and Load Disturbances*  
Masoud Vaezi and Afshin Izadian

Utility Applications V, Chair: Olivier Trescases, Srdjan Lukic, Room: 202A 175

3:30PM *Field Upgradeable Transformer: A Fractionally-Rated Voltage Regulator for the Distribution System*  
Rajendra Prasad Kandula, Hao Chen, Anish Prasai, Joe Schatz and Deepak Divan

3:55PM *New Configuration of Multi-Functional Grid-Connected Inverter to Improve Both Current-Based and Voltage-Based Power Quality*  
Wooyoung Choi, Woongkul Lee, Di Han and Bulent Sarlioglu

4:20PM *Model Predictive Control of A Matrix-Converter Based Solid State Transformer for Utility Grid Interaction*  
Yushan Liu, Haitham Abu-Rub, Baoming Ge, Robert S. Balog and Yaosuo Xue

4:45PM *A Triple Port Active Bridge Converter based Power Electronic Transformer*  
Venkat Nag Someswar Rao Jakka and Anshuman Shukla

Modeling, Analysis, and Control of Grid-Connected Converters IV, Chair: Paolo Mattavelli, John Lam, Room: 202D 176

3:30PM *Evaluation of Active Islanding Detection Based Methods Under Non-Liner-loads Scenarios*  
David Reigosa, Cristian Blanco, Juan Manuel Guerrero and Fernando Briz

3:55PM *Decentralized Adaptive Control for Interconnected Boost Converters based on backstepping approach*  
Arturo Hernandez-Mendez, Jesus Linares-Flores and Hebertt Sira-Ramirez

4:20PM *Impedance Synthesis by Inverter Control for Active Loads in Anti-Islanding Testbenches*  
Tommaso Caldognetto, Luca Dalla Santa, Paolo Magnone and Paolo Mattavelli

4:45PM *A Unified Impedance Model of Voltage-Source Converters with Phase-Locked Loop Effect*  
Xiongfei Wang, Lennart Harnefors, Frede Blaabjerg and Poh Chiang Loh

More Electric Aircraft, Chair: Pat Wheeler, Bulent Sarlioglu, Room: 102D 176

3:30PM *An Induction Generator based Auxiliary Power Unit for Power Generation and Management System for More Electric Aircraft*  
Yijiang Jia and Kaushik Rajashekara

3:55PM *Design and Optimization of a High Performance Isolated Three Phase AC/DC Converter for Aircraft Applications*  
Qiong Wang, Xuning Zhang, Rolando Burgos, Dushan Boroyevich, Adam White and Mustansir Kheraluwala

4:20PM *Taking into account interactions between converters in the design of aircraft power networks*  
Qian Li, Andrea Formentini, Arnaud Baraston, Xuning Zhang, Pericle Zanchetta, Jean-Luc Schanen and Dushan Boroyevich

4:45PM *Stability Assessment of A Droop-Controlled Multi-Generator System in the More Electric Aircraft Using Parameter Space Approach*  
Fei Gao, Xiancheng Zheng and Serhiy Bozhko

DC-DC Converters: High Frequency, Chair: Seth Sanders, Juan Rivas-Davila, Room: 102C 177

3:30PM *A GaN-Based Partial Power Converter with MHz Reconfigurable Switched-Capacitor and RF SEPIC*  
Junjian Zhao and Yehui Han

3:55PM *Monolithic Multilevel GaN Converter for Envelope Tracking in RF Power Amplifiers*  
Alihossein Sepahvand, Parisa Momen Roodaki, Yuanzhe Zhang, Zoya Popovic and Dragan Maksimovic

4:20PM *An Improved PDM Control Method for a High Frequency Quasi-Resonant Converter*  
Hossein Mousavian, Alireza Bakhshai and Praveen Jain

4:45PM *Automotive LED Driver Based On High Frequency Zero Voltage Switching Integrated Magnetics Cuk Converter*  
Alihossein Sepahvand, Montu Doshi, James Patterson, Vahid Yousefzadeh, Khurram Afridi and Dragan Maksimovic

Modeling and Control of AC-DC Converters, Chair: Pragasen Pillay, Lixiang Wei, Room: 202E 178

3:30PM *Dynamic Response Optimization for Three-phase VIENNA Rectifier with Load Feedforward Control*  
Xudong Chen, Xiaoyong Ren, Zhiliang Zhang, Qianhong Chen and Xinbo Ruan

3:55PM *A Compensation Scheme to Reduce Input Current Distortion in GaN Based 450 kHz Three-Phase Vienna Type PFC*  
Bo Liu, Ren Ren, Edward Andrew Jones, Fred Wang, Daniel Jes Costinett and Zheyu Zhang

4:20PM *Modeling and Analysis for Input Characteristics of Line-Frequency Rectifiers*  
Xiaolong Yue, Dushan Boroyevich, Rolando Burgos and Fang Zhuo

4:45PM *Hybrid Damping for Active Front End Converter*  
Yogesh Patel, Sayed Ahmed Ahmed and Lixiang Wei

Converter Control in Microgrids and Distributed Generation, Chair: Leon M Tolbert, Shu-hung Chung, Room: 203DE 178

3:30PM *A Feed-forward Based Harmonic Compensation Approach for Low Switching Frequency Grid Interfacing VSI*  
Hao Tian and Yun Wei Li

3:55PM *An Embedded Voltage Harmonic Compensation Strategy for Current-Controlled DG Interfacing Converters*  
Xin Zhao, Lexuan Meng, Chuan Xie, Josep Guerrero, Mehdi Savaghebi, Juan Vasquez and Xiaohua Wu

4:20PM *Analysis and Damping of harmonic propagation in DG-Penetrated distribution networks*  
Jinghang Lu, Mehdi Savaghebi and Josep Guerrero

4:45PM *Voltage and Current Regulators Design of Power Converters in Islanded Microgrids based on State Feedback Decoupling*  
Federico de Bosio, Luiz Antonio de Souza Ribeiro, Francisco Freijedo, Josep Guerrero and Michele Pastorelli

Reliability, Diagnostic and Faults Analysis in Power Converters II, Chair: Marco Liserre, Lee Empringham, Room: 102E 179

3:30PM *Computation and Analysis of Dielectric Losses in MV Power Electronic Converter Insulation*  
Thomas Guillod, Raphael Faerber, Florian Krismer, Christian M. Franck and Johann W. Kolar

3:55PM *Computational Light Junction Temperature Estimator for Active Thermal Control*  
Markus Andresen, Mike Schloh, Giampaolo Buticchi and Marco Liserre

4:20PM *Fast Fault Diagnosis and identification Method for Boost Converter Based on Inductor Current Emulator*  
Elham Pozouki, Alexis De Abreu-Garcia and Yilmaz Sozer

4:45PM *Modeling and Improvement of Thermal Cycling in Power Electronics for Motor Drive Applications*  
Ionut Vernica, Ke Ma and Frede Blaabjerg

Reliability and Fault Tolerance in Multilevel Converters, Chair: Sheldon Williamson, Christian Klumpner, Room: 202B 180

3:30PM *Highly Reliable Transformerless Neutral Point Clamped Inverter with Separated Inductors*  
Liwei Zhou, Feng Gao, Guang Shen and Mengxing Chen

3:55PM *Fault Detection and Tolerant Control of Open-circuit Failure in MMC with Full-bridge Sub-modules*  
Kai Li, Zhengming Zhao, Liqiang Yuan, Sizhao Lu and Ye Jiang

4:20PM *Control Strategy of Single Phase Back-to-back Converter for Medium Voltage Drive under Cell Fault Condition*  
Yoon-Ro Lee, Jeong-Mock Yoo, Hyun-Sam Jung and Seung-Ki Sul

4:45PM *Fault Tolerance Analysis for the 5-Level Unidirectional T-Rectifier*  
Alessandro Lidozzi, Marco Di Benedetto, Luca Solero, Fabio Crescimbini and Petar Grbovic

Electric Machines for Automotive Applications III, Chair: Julia Zhang, Jie Shen, Room: 102B 181

3:30PM *Design of a Wound Field Synchronous Machine for Electric Vehicle Traction with Brushless Capacitive Field Excitation*  
Antonio Di Gioia, Ian P. Brown, Ryan Knippel, Daniel C. Ludois, Yue Nie, Jiejian Dai, Skyler Hagen and Christian Alteheld

3:55PM *Design and Development of a MLS Based Compact Active Suspension System, Featuring Air Spring and Energy Harvesting Capabilities*  
Nick Ilsoe Berg, Rasmus Koldborg Holm and Peter Omand Rasmussen

4:20PM *A Simple Design Method for Surface-mounted PM machines for Traction Application*  
Chao Lu and Gianmario Pellegrino

4:45PM *Design Optimization of Spoke-Type PM Motors for Formula E Racing Cars*  
Alireza Fatemi, Dan Ionel, Mircea Popescu and Nabeel Demerdash

PM Machines IV, Chair: Leila Parsa, Radu Bojoi, Room: 101A 181

3:30PM *Tolerance Study to Forecast Performances of Permanent Magnet Synchronous Machines Using Segmented Stator for Mass Production*  
TaeSik Kim, Mazharul Chowdhury, Mohammad Islam, Abraham Gebregergis and Tomy Sebastian

3:55PM *Permanent Magnet Material and Pulsating Torque Minimization in Spoke Type Interior PM Machines*  
Zhentao Stephen Du and Thomas Anthony Lipo

4:20PM *Mechanical Design Method for a High-Speed Surface Permanent Magnet Rotor*  
Erik Schubert and Bulent Sarlioglu

4:45PM *Analysis and Design of Triple-Rotor Axial-Flux Spoke-Array Vernier Permanent Magnet Machines*  
Rui Zhang, Jian Li, Ronghai Qu and Dawei Li

Energy Efficient Motor Drives, Chair: Francisco Canales, Dong Jiang, Room: 101B 182

3:30PM *Electrical Loss Minimization Technique for Wind Generators based on a Comprehensive Dynamic Modelling of Induction Machines*  
Maria Carmela Di Piazza, Massimiliano Luna and Marcello Pucci

3:55PM *Maximum Efficiency Control Method in 7-phase BLDC Motor by Changing the Number of the Excited Phase Windings*  
Sang-Woo Park, Hyung-Seok Park, Jong-Joo Moon, Won-Sang Im and Jang-Mok Kim

4:20PM *Control Strategy for Dual Three-Phase PMSMs With Minimum Losses in the Full Torque Operation Range Under Single Open-Phase Fault*  
Fernando Baneira, Jesus Doval-Gandoy, Alejandro Yepes, Oscar Lopez and Diego Perez-Estevez

4:45PM *A Multi-Pulse Front-End Rectifier System with Electronic Phase-Shifting for Harmonic Mitigation in Motor Drive Applications*  
Firuz Zare, Pooya Davari and Frede Blaabjerg

Sensorless Drives II, Chair: Fernando Briz, Giacomo Scelba, Room: 101CD 183

3:30PM *A Robust Magnetic Polarity Self-Sensing Method for Start-Up of PM Synchronous Machine in Fan-Like System*  
Wei Sun, Jian-Xin Shen, Meng-Jia Jin and He Hao

3:55PM *Universal Sensorless Vector Control Applicable to Line-Start Permanent Magnet Synchronous Motors with Damper Winding*  
Shu Yamamoto, Hideaki Hirahara, Akira Tanaka and Takahiro Ara

4:20PM *Improvement of Back-EMF Self-Sensing for Induction Machines when using Deadbeat-Direct Torque and Flux Control (DB-DTFC)*  
Kang Wang, Noor Baloch and Robert Lorenz

4:45PM *Sensorless Position Control of PMSM Operating at Low Switching Frequency for High Efficiency Climate Control Systems*  
Parag Kshirsagar and R. Krishnan

Silicon and WBG Devices, Chair: Jerry Hudgins, Enrico Santi, Room: 202C 183

3:30PM *SuperJunction Cascode, a Configuration to Break the Silicon Switching Frequency Limit*  
Juan Rodriguez, Jaume Roig, Alberto Rodriguez, Ignacio Castro, Diego G. Lamar and Filip Bauwens

3:55PM *Maximizing the Performance of 650 V p-GaN Gate HEMTs: Dynamic Ron Characterization and Gate-Drive Design Considerations*  
Hanxing Wang, Ruiliang Xie, Cheng Liu, Jin Wei, Gaofei Tang and Kevin. J Chen

4:20PM *15kV/40A FREEDM Super-Cascode: A Cost Effective SiC High Voltage and High Frequency Power Switch*  
Xiaoqing Song, Alex Huang, Zhang Liqi, Liu Pengkun and Xijun Ni

4:45PM *A Study of Dynamic High Voltage Output Charge Measurement for 15 kV SiC MOSFET*  
Li Wang, Qianlai Zhu, Wensong Yu and Alex.Q Huang

Distribution-System Utility Interface Topics, Chair: Tsorng-Juu Liang, Deepak Divan, Room: 102A 184

3:30PM *Unbalanced Voltage Compensation in LV Residential AC Grids*  
Ionut Trintis, Philip Douglass and Stig Munk-Nielsen

3:55PM *The Hierarchical Energy Management Control for Residential Energy Harvesting System*  
Shuang Zhao, Yuzhi Zhang, Joe Moquin and Alan Mantooth

4:20PM *Reactive Power Distribution Strategy using Power Factor Correction Converters for Smart Home Application*  
S M Rakiul Islam, Shawn Maxwell, Md. Kamal Hossain, Sung-Yeul Park and Sungmin Park

4:45PM *Active Voltage Balancing Control for Multi HV-IGBTs in Series Connection*  
Shiqi Ji, Zhengming Zhao, Ting Lu, Fred Wang, Leon Tolbert and Hualong Yu

Thursday, September 22, 8:30AM-10:10AM

Converter Topologies for Wind Power Systems, Chair: Akshay Kumar Rathore, Yilmaz Sozer, Room: 203AB 185

8:30AM *The DOE Next-Generation Drivetrain for Wind Turbine Applications: Gearbox, Generator, and Advanced Si/SiC Hybrid Inverter System*  
William Erdman and Jonathan Keller

8:55AM *Inductorless Boost Rectifier for Small Power Wind Energy Converters*  
Carlos Lumbreras, Juan Manuel Guerrero, David Reigosa, Daniel Fernandez and Fernando Briz

9:20AM *High-frequency Isolated DC-DC Converter for Offshore Wind Energy Systems*  
Kumar Modepalli, Rohit Suryadevara and Leila Parsa

9:45AM *A New Three-phase AC/DC High Power Factor Soft-switched Step-up Converter with High Gain Rectifier Modules for Medium Voltage Grid in Wind Systems*  
Mehdi Abbasi and John Lam

Energy Storage Systems, Chair: Adel Nasiri, Tsai-Fu Wu, Room: 203C 186

8:30AM *A Comparison of Broadband Impedance Measurement Techniques for Lithium-Ion Batteries*  
Alfred Waligo and Paul Barendse

8:55AM *Evaluation of Lithium-ion Battery Second Life Performance and Degradation*  
Egoitz Martinez-Laserna, Elixabet Sarasketa-Zabala, Daniel-Ioan Stroe, Maciej Swierczynski, Alexander Warnecke, Jean-Marc Timmermans, Shovon Goutam and Pedro Rodriguez

9:20AM *A Distributed ESO based Cooperative Current-Sharing Strategy for Parallel Charging Systems Under Disturbances*  
Zhou Yanhui, Huang Zhiwu, Liu Weirong, Li Heng and Hongtao Liao

9:45AM *A Comprehensive Study on the Degradation of Lithium-Ion Batteries during Calendar Ageing: The Internal Resistance Increase*  
Daniel Stroe, Maciej Swierczynski, Soren Kaer and Remus Teodorescu

Power Quality I, Chair: Jonathan Kimball, Dao Zhou, Room: 101B 186

8:30AM *Enhanced Power Quality and Minimized Peak Current Control in An Inverter based Microgrid under Unbalanced Grid Faults*  
Wenzhao Liu, Xiaoqiang Guo, Giorgio Sulligoi, Yajuan Guan, Xin Zhao, Baoze Wei, Mehdi Savaghebi and Josep M Guerrero

8:55AM *Parallel Interfacing Converters under Unbalanced Voltage: Active Power Oscillation Cancellation with Peak Current Sharing*  
Farzam Nejabatkhah and Yunwei (Ryan) Li

9:20AM *The Reverse Zero-Sequence Current Compensation Strategy for Back-to-Back Active Power Conditioners*  
Tung Yueh, Terng-Wei Tsai, Yaow-Ming Chen, Yih-Der Lee and Yung-Ruei Chang

9:45AM *Harmonic Mitigation in Interphase Power Controllers Using Passive Filter-Based Phase Shifting Transformer*  
Mohammad Amin Chitsazan and Andrzej M Trzynadlowski

AC Microgrids I: Modelling and Stability, Chair: Adel Nasiri, Reza Ahmadi, Room: 203DE 187

8:30AM *Modeling and Stability Analysis of the Small-AC-Signal Droop Based Secondary Control for Islanded Microgrids*  
Teng Wu, Zeng Liu, Jinjun Liu, Baojin Liu and Shike Wang

8:55AM *A Small-AC-Signal Injection Based Harmonic Power Sharing Method for Islanded Microgrids*  
Baojin Liu, Zeng Liu, Jinjun Liu, Teng Wu, Shike Wang and Xin Meng

9:20AM *Improvement of Transient Stability in Inverter-Based AC Microgrid via Adaptive Virtual Inertia*  
XiaoChao Hou, Hua Han, Chaolu Zhong, Wenbin Yuan, Meijie Yi and Ying Chen

9:45AM *Frequency Support Properties of the Synchronous Power Control for Grid-Connected Converters*  
Weiyi Zhang, Daniel Remon, Joan Rocabert, J. Ignacio Candela, Alvaro Luna and Pedro Rodriguez

Battery Management for Transportation Electrification I, Chair: Yilmaz Sozer, Berker Bilgin, Room: 102D 188

8:30AM *A Pack-to-Cell-to-Pack Battery Equalizer with Soft-Switching Based on Buck-Boost and Bidirectional LC Resonant Converters*  
Zeyuan Li, Yunlong Shang, Bin Duan and Chenghui Zhang

8:55AM *A New Perspective on Battery Cell Balancing: Thermal Balancing and Relative Temperature Control*  
Ye Li and Yehui Han

9:20AM *Advanced Cell-level Control for Extending Electric Vehicle Battery Pack Lifetime*  
Muhammad Muneeb Ur Rehman, Fan Zhang, Michael Evzelman, Regan Zane, Kandler Smith and Dragan Maksimovic

9:45AM *A Battery Cell Balancing Control Scheme with Minimum Charge Transfer*  
Zhiyuan Shen, Handong Gui and Leon Tolbert

Grid Connected Single-Phase Inverters, Chair: Mahshid Amirabadi, Fernando Briz, Room: 202A 189

8:30AM *Double Line Frequency Ripple Cancelling for Single-Phase Quasi-Z-Source Inverter*  
Yuan Li, Wenqiang Gao, Jiayi Li, Rui Zhang and Fan Fang

8:55AM *Hybrid control scheme for the current loop of a grid connected inverter operating with highly distorted grid voltage*  
Julio Cesar Viola, Jose Restrepo, Jose Manuel Aller and Flavio Quizhpi

9:20AM *Single-Phase LLCL-Filter-based Grid-Tied Inverter with Low-Pass Filter Based Capacitor Current Feedback Active damper*  
Liu Yuan, Wu Weimin, He Yuanbin, Chung Shu-Hung and Blaabjerg Frede

9:45AM *A single-phase tri-state integrated Buck-Boost inverter suitable to operate in grid-connected and island modes*  
Jose Carlos Pena, Cindy Paola Guzman and Carlos Alberto Canesin

Modular Multilevel Converters (MMC) I, Chair: Jiangchao Qin, Wim van der Merwe, Room: 202B 189

8:30AM *DC Fault Ride Through of Multilevel Converters*  
Geraint Chaffey, Paul Judge, Michael Merlin, Philip Clemow and Tim Green

8:55AM *Reverse Blocking Sub-Module Based Modular Multilevel Converter with DC Fault Ride-Through Capability*  
Xiaofeng Yang, Yao Xue, Bowei Chen, Zhiqin Lin, Yajie Mu, Trillion Q. Zheng and Seiki Igarshi

9:20AM *Closed-loop Control of the DC-DC Modular Multilevel Converter*  
Heng Yang and Maryam Saeedifard

9:45AM *New MMC Capacitor Voltage Balancing using Sorting-less Strategy in Nearest Level Control*  
Mattia Ricco, Laszlo Mathe and Remus Teodorescu

DC-DC Isolated: LLC, Chair: Jason Stauth, Vladimir Blasko, Room: 102C 190

8:30AM *A New Tightly Regulated Dual Output LLC Resonant Converter with PFM plus Phase-shift Control*  
Xun Gao, Hongfei Wu, Yan Xing, Haibing Hu and Yu Zhang

8:55AM *Analytical Model for LLC Resonant Converter With Variable Duty-Cycle Control*  
Yanfeng Shen, Huai Wang, Frede Blaabjerg, Xiaofeng Sun and Xiaohua Li

9:20AM *Three-Phase LLC Resonant Converter with Integrated Magnetics*  
Wilmar Martinez, Noah Mostafa, Yuki Itoh, Masayoshi Yamamoto, Jun Imaoka, Kazuhiro Umetani, Kimura Shota, Nanamori Kimihiro and Endo Shun

9:45AM *Accurate ZVS Boundary in High Switching Frequency LLC Converter*  
Ren Ren, Liu Bo, Jones Edward Andrew, Wang Fred, Costinett Daniel Jes and Zhang Zheyu

Modeling and Control of Grid Connected Converter I, Chair: Sung Yeul Park, Fernando Briz, Room: 202D 191

8:30AM *A Unified Control of Back-to-Back Converter*  
Alberto Rodriguez-Cabero, Francisco Huerta Sanchez and Milan Prodanovic

8:55AM *Control of an Islanded Power-Electronic Converter as an Oscillator*  
Ricardo Perez, Cesar Silva and Amirnaser Yazdani

9:20AM *Power control for Grid-connected Converter to Comply with Safety Operation Limits during Grid Faults*  
Shida Gu, Xiong Du, Ying Shi, Yue Wu, Pengju Sun and Heng-Ming Tai

9:45AM *An online measurement method for common-mode impedance in three-phase grid-connected converters*  
Tuomas Messo, Tomi Roinila, Jukka Viinamaki and Teuvo Suntio

Fault Prognosis for Power Devices, Chair: Marco Liserre, Juan Rivas-Davila, Room: 102E 191

8:30AM *Remaining Useful Lifetime Estimation For Thermally Aged Power Mosfets With Ransac Denoising Algorithm*  
Serkan Dusmez, Mehrdad Heydarzadeh, Mehrdad Nourani and Bilal Akin

8:55AM *An Analytical Model for False Turn-On Evaluation of GaN Transistor in Bridge-Leg Configuration*  
Ruiliang Xie, Hanxing Wang, Gaofei Tang, Xu Yang and Kevin. J Chen

9:20AM *Advanced Condition Monitoring System Based on On-Line Semiconductor Loss Measurements*  
Tobias Krone, Lan Dang Hung, Marco Jung and Axel Mertens

9:45AM *A Comprehensive Study on Variations of Discrete IGBT Characteristics Due to Package Degradation Triggered by Thermal Stress*  
Syed Huzaif Ali, Serkan Dusmez and Bilal Akin

Thermal Analyses of Electric Machines, Chair: Bulent Sarlioglu, Patel Bhageerath Reddy, Room: 102B 192

8:30AM *Experimental Calibration in Thermal Analysis of PM Electrical Machines*  
Sabrina Ayat, Rafal Wrobel, James Goss and David Drury

8:55AM *Thermal Conductivity Evaluation of Fractional-Slot Concentrated-Winding Machines*  
Aldo Boglietti, Silvio Vaschetto, Marco Cossale and Thiago Dutra

9:20AM *Thermal Performance Modeling of Foil Wound Concentrated Coils in Electric Machines*  
Michael Rios, Giri Venkataramanan, Annette Muetze and Heinrich Eickhoff

9:45AM *Experimental Validation in Operative Conditions of Winding Thermal Model for Short-Time Transient*  
Aldo Boglietti, Silvio Vaschetto, Marco Cossale and Thiago Dutra

Transverse Flux Machines, Chair: Keith Corzine, Daniel Ludois, Room: 101A 193

8:30AM *A Hybrid-Excited Axial Transverse Flux Permanent Magnet Machine*  
Emrullah Aydin, Ju Hyung Kim, Emin Yildiriz, Mehmet Timur Aydemir and Bulent Sarlioglu

8:55AM *Reduction of Cogging Torque in Transverse Flux Machines by Stator and Rotor Pole Shaping*  
Cristofaro Pompermaier, Jamie Washington, Lars Sjoeberg and Nabeel Ahmed

9:20AM *Design Considerations of a Transverse Flux Machine for Direct Drive Wind Turbine Applications*  
Tausif Husain, Iftekhar Hasan, Yilmaz Sozer, Iqbal Husain and Eduard Muljadi

9:45AM *Analytical Model Based Design Optimization of a Transverse Flux Machine*  
Iftekhar Hasan, Tausif Husain, Yilmaz Sozer, Iqbal Husain and Eduard Muljadi

Control of Electric Drives II, Chair: Marko Hinkkanen, Pinjia Zhang, Room: 101CD 194

8:30AM *A Novel Six-Phase Inverter System for High-Power Synchronous Motor Drives*  
Yumei Song, Xiaojie You, Xizheng Guo and Jian Wang

8:55AM *State-Space Flux-Linkage Control of Bearingless Synchronous Reluctance Motors*  
Seppo Saarakkala, Maksim Sokolov, Marko Hinkkanen, Jari Kataja and Kari Tammi

9:20AM *Current Harmonic Compensation for n-Phase Machines With Asymmetrical Winding Arrangement*  
Alejandro G. Yepes, Jesus Doval-Gandoy, Fernando Baneira, Diego Perez-Estevez and Oscar Lopez

9:45AM *Post-fault operation strategy for single switch open circuit faults in electric drives*  
Heinrich T. Eickhoff, Roland Seebacher, Annette Muetze and Elias G. Strangas

Power Packaging , Chair: Douglas C Hopkins, Giuseppe Chimento, Room: 202C 194

8:30AM *A Quasi-online Method of Thermal Network Parameter Identification of IGBT Module*  
Tengfet Li, Xiong Du, Cheng Zeng, Pengju Sun and Heng-Ming Tai

8:55AM *Direct-cooled power module with a thick Cu heat spreader featuring a stress-suppressed structure for EV/HEV inverters*  
Keiichiro Numakura, Kenta Emori, Yusuke Yoshino, Yasuaki Hayami and Tetsuya Hayashi

9:20AM *Impact of Poly-Crystalline Diamond within Power Semiconductor Device Modules in a Converter*  
Mark Robert Sweet, Kalyani Menon and Ekkanath Madathil Sankar Narayanan

9:45AM *A Novel 3D Structure for Synchronous Buck Converter Based on Nitride Gallium Transistors*  
Clement Fita, Pierre-Olivier Jeannin, Pierre Lefranc, Edith Clavel and Johan Delaine

Magnetics I, Chair: John Siefken, Charles Sullivan, Room: 102A 195

8:30AM *NiCuZn Ferrite Cores by Gelcasting: Processing and Properties*  
Lanbing Liu, Yi Yan, Khai Ngo and Guo-Quan Lu

8:55AM *Low-Capacitance Planar Spiral Windings Employing Inverse Track-Width-Ratio*  
Samuel Robert Cove and Martin Ordonez

9:20AM *On-Chip Transformers with Shielding Structures for High dV/dt Immunity Isolated Gate Drive*  
Rongxiang Wu, Julong Chen, Niteng Liao and Xiangming Fang

9:45AM *Additive Manufacturing of Toroid Inductor for Power Electronics Applications*  
Yi Yan, Khai Ngo, Yunhui Mei, Guo-Quan Lu and Jim Moss

Grid Synchronization, Chair: Behrooz Mirafzal, Tsorng-Juu Liang, Room: 202E 196

8:30AM *A New Phase-Locked Loop Method for Three-Phase System*  
Hongyan Zhao, Trillion Q. Zheng, Yan Li, Hong Li and Shi Pu

8:55AM *A New Second-Order Generalized Integrator Based Quadrature Signal Generator With Enhanced Performance*  
Zhen Xin, Zian Qin, Minghui Lu, Poh Chiang Loh and Frede Blaabjerg

9:20AM *A Modified SRF-PLL for Phase and Frequency Measurement of Single-Phase Systems*  
Md. Rasheduzzaman, Sami Khorbotly and Jonathan Kimball

9:45AM *Influence Of Double-Line Frequency Power Oscillation In Photovoltaic Generator Efficiency And H-Bridge VSI Performance*  
Luciano Alves, Montie Vitorino, Marcus Oliveira, Mauricio Correa and Gutemberg Goncalves

Thursday, September 22, 10:30AM-12:10PM

Electric Machines for Wind Power Systems, Chair: Ion Boldea, Pragasen Pillay, Room: 203AB 196

10:30AM *Comparison Analysis of PM Transverse Flux Outer Rotor Machines with and without Magnetic Shunts*  
Oleksandr Dobzhanskyi, Gouws Rupert and Amiri Ebrahim

10:55AM *A Generator-Converter Design for Direct Drive Wind Turbines*  
Akanksha Singh and Behrooz Mirafzal

11:20AM *Gearbox Fault Diagnosis Using Vibration and Current Information Fusion*  
Yayu Peng, Wei Qiao, Liyan Qu and Jun Wang

11:45AM *Bearing Fault Diagnosis of Direct-Drive Wind Turbines Using Multiscale Filtering Spectrum*  
Jun Wang, Yayu Peng and Wei Qiao

Converter Topologies for Energy Storage Systems, Chair: Behrooz Mirafzal, Ion Boldea, Room: 203C 197

10:30AM *Design Considerations of an Isolated GaN Bidirectional DC-DC Converter*  
Fei Xue, Ruiyang Yu and Alex Q. Huang

10:55AM *Flexbattery - Merging Multilevel Power Conversion and Energy Storage*  
Erik Lemmen, Jorge L. Duarte and Elena A. Lomonova

11:20AM *A Novel Modular Dual Active Bridge (DAB) DC-DC Converter with DC Fault Ride-Through Capability for Battery Energy Storage Systems*  
Yuxiang Shi and Hui Li

11:45AM *A High Current Bidirectional DC-DC Converter for Concept Demonstration of Grid-Scale SMES Systems*  
Yu Du, Eddy Aeloiza and VR V. Ramanan

AC Microgrids II: Sharing and Coordination, Chair: Pedro Rodriguez, Hui Li, Room: 203DE 198

10:30AM *Harmonic power sharing with Voltage Distortion Compensation of Droop Controlled Islanded Microgrids*  
Hassan Moussa, Jean-Philippe Martin, Serge Pierfederici and Nazih Moubayed

10:55AM *Novel Active Synchronization Strategy for Multi-Bus Microgrid with Distributed Cooperation Control*  
Chaolu Zhong, Yao Sun, Ying Chen, Mi Dong, Ming Liu and Xiaochao Hou

11:20AM *An Inverter-Current-Feedback based Reactive Power Sharing Method for Parallel Inverters in Microgrid*  
Qicheng Huang and Kaushik Rajashekara

11:45AM *Distributed Voltage Control and Load Sharing for Inverter-Interfaced Microdrid with Resistive Lines*  
Mohammad S. Golsorkhi, Qobad Shafiee, Dylan D.C. Lu and Josep M. Guerrero

Batteries and Battery Management for Transportation Electrification II, Chair: Oliver Gross, Omer Onar, Room: 102D 199

10:30AM *Accurate Battery Parameter Estimation with Improved Continuous Time System Identification Methods*  
Bing Xia, Xin Zhao, Raymond de Callafon, Hugues Garnier, Truong Nguyen and Chris Mi

10:55AM *A Real World Technology Testbed for Electric Vehicle Smart Charging Systems and PEV-EVSE Interoperability Evaluation*  
Theodore Bohn and Hal Glenn

11:20AM *Modeling of Low-Temperature Operation of a Hybrid Energy Storage System with a Butler-Volmer Equation Based Battery Model*  
Phillip Kollmeyer, Anantharaghavan Sridhar and Thomas Jahns

11:45AM *Voltage and Current Signals De-noising with Wavelet Transform Matrix for Improved SOC Estimation of Lithium-ion Battery*  
Xiang Cheng, Zhouyu Lu, Zhiliang Zhang, Dongjie Gu and Yang Yang

Multi-Phase Inverter, Chair: Babak Parkhideh, Raja Ayyanar, Room: 202A 199

10:30AM *Improved r-Z-Source Inverter*  
Zeeshan Aleem and Moin Hanif

10:55AM *High-Frequency Six Pulse DC Link Based Bidirectional Three-Phase Inverter without Intermediate Decoupling Capacitor*  
Vatta Kkuni Kanakesh, Anirban Ghoshal, Dorai Babu Yelaverthy, Akshay Kumar Rathore and Ranjit Mahanty

11:20AM *Closed-Form Equations for Analytical Exploration and Comparison of Switching Power Losses in Flying Capacitor Multicell and Active Neutral-Point-Clamped Multilevel Converters*  
Vahid Dargahi, Arash Khoshkbar Sadigh and Keith Corzine

11:45AM *Advanced Three Level Active Neutral Point Converter with Fault Tolerant Capabilities*  
Ramin Katebi, Andrew Stark, Jiangbiao He and Nathan Weise

AC-AC Converters I, Chair: Pat Wheeler, Mattia Ricco, Room: 202E 200

10:30AM *A Novel Highly Reliable Three Phase Buck-Boost AC-AC Converter*  
Ashraf Ali Khan and Honnyong Cha

10:55AM *Hybrid Bidirectional AC/AC Multilevel Converter*  
Ramiar Alaei, S. Ali Khajehoddin and Wilsun Xu

11:20AM *A Reliable Cascaded AC-AC Converter*  
Ashraf Ali Khan, Honnyong Cha, Sanghoon Kim and Hafiz Furqan Ahmed

11:45AM *Parallel AC-AC Three-Phase with Shared-Leg Converters*  
Edgard Fabricio, Cursino Jacobina, Nady Rocha, Rodolpho Cavalcante and Mauricio Correa

Modular Multilevel Converters (MMC) II, Chair: Juergen Biela, Grain Adam, Room: 202B 201

10:30AM *A Series HVDC Power Tapping Using Modular Multilevel Converters*  
Binbin Li, Mingxu Guan, Dianguo Xu, Rui Li, Grain Philip Adam and Barry Williams

10:55AM *A Zero-sequence Voltage Injection Control Scheme for Modular Multilevel Converter Under Submodule Failure*  
Jinke Li, Xuezhi Wu, Xiuyuan Yao, Long Jing, Xinmin Jin, Wen Wu, Xiaoxing Wang and Shuai Wang

11:20AM *An Interconnected Observer for Modular Multilevel Converter*  
Mohamed Trabelsi, Malek Ghanes, Omar Ellabban, Haitham Abu-Rub and Lazhar Ben-Brahim

11:45AM *DC Bus Balancing Control Techniques for the Cascaded Neutral Point Clamped Modular Converter*  
Meng-Jiang Tsai, Wei-Lun Huang, Hsin-Chih Chen, Ping-Heng Wu and Po-Tai Cheng

DC-DC Isolated: Resonant, Chair: Dragan Maksimovic, Yan-Fei Liu, Room: 102C 201

10:30AM *Step-Down Impedance Control Network Resonant DC-DC Converter Utilizing an Enhanced Phase-Shift Control for Wide-Input-Range Operation*  
Jie Lu, Ashish Kumar and Khurram Afridi

10:55AM *Soft-Switching Push-Pull Converter with Parallel Resonant Link and Buck-Boost Capability*  
Morteza Moosavi and Hamid A. Toliyat

11:20AM *Bidirectional Series-Resonant DC-DC Converter with Fault-Tolerance Capability for Smart Transformer*  
Levy Costa, Giampaolo Buticchi and Marco Liserre

11:45AM *Analysis and Design of Planar Inductor and Transformer for Resonant Converter*  
Yueshi Guan, Na Qi, Yijie Wang, Xiangjun Zhang, Dianguo Xu and Wei Wang

Modeling and Control of Grid Connected Converter II, Chair: Dragan Maksimovic, Matthias Preindl, Room: 202D 202

10:30AM *Combined DC Voltage Control Scheme for Three-port Energy Router Based on Instantaneous Energy Balance*  
Gaohui Feng, Zhengming Zhao, Liqiang Yuan and Kai Li

10:55AM *Grid-Voltage Sensorless Control of a Converter Under Unbalanced Conditions: On the Design of a State Observer*  
Jarno Kukkola and Marko Hinkkanen

11:20AM *Current-Mode Boundary Controller with Reduced Number of Current Sensors for a Three-Phase Inverter*  
He Yuanbin, Chung Shu-hung, Ho Ngai-man and Wu Weimin

11:45AM *Positive- and Negative-Sequence Current Controller for Grid-Tied Converters With LCL Filters*  
Diego Perez-Estevez, Jesus Doval-Gandoy, Alejandro Yepes, Oscar Lopez and Fernando Baneira

Power Quality II, Chair: Luca Solero, Maurizio Cirrincione, Room: 101B 203

10:30AM *Realization of Quadrature Signal Generator Using Accurate Magnitude Integrator*  
Zhen Xin, Changwoo Yoon, Rende Zhao, Poh Chiang Loh and Frede Blaabjerg

10:55AM *A New Instantaneous Point on Wave Voltage Sag Detection Algorithm and Validation*  
Yujia Cui, Ahmed Sayed-Ahmed, Prathamesh Vadhavkar, Brian Seibel and Russel Kerkman

11:20AM *Voltage Quality Enhancement with Minimum Power Injection*  
Darlan Fernandes, Fabiano Costa, Joao Martins, Alberto Lock, Edison da Silva and Montie Vitorino

11:45AM *A Universal Variable On-time Compensation to improve THD of High-frequency CRM Boost PFC Converter*  
Zhehui Guo, Xiaoyong Ren, Handong Gui, Yu Wu, Zhiliang Zhang and Qianhong Chen

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10:30AM *On Impedance Modeling of Single-Phase Voltage Source Converters*  
Shahil Shah and Leila Parsa

10:55AM *Design Consideration of Volt-VAR Controllers in Distribution Systems with Multiple PV Inverters*  
Mahsa Ghapandar Kashani, Yonghwan Cho and Subhashish Bhattacharya

11:20AM *Extended Stable Boundary of LCL-Filtered Grid-Connected Inverter Based on Grid-Voltage Feedforward Control*  
Minghui Lu, Zhen Xin, Xiongfei Wang, Remus Beres and Frede Blaabjerg

11:45AM *Allowable Bus Impedance Region for MVDC Distribution Systems and Stabilizing Controller Design Using Positive Feed-Forward Control*  
Jonathan Siegers, Silvia Arrua and Enrico Santi

Non-Conventional Machine Configurations I, Chair: Robert D. Lorenz, Ronghai Qu, Room: 101A 204

10:30AM *A Novel Stator-Consequent-Pole Memory Machine*  
Yang Hui, Lin Heyun, Zhu Z. Q., Fang Shuhua and Huang Yunkai

10:55AM *A Novel Variable Flux Memory Machine with Series Hybrid Magnets*  
Hao Hua, Z.Q. Zhu, Adam Pride, Rajesh Deodhar and Toshinori Sasaki

11:20AM *On the Feasibility of Carbon Nanotube Windings for Electrical Machines - Case Study for a Coreless Axial Flux Motor*  
Vandana Rallabandi, Narges Taran, Dan M. Ionel and John F. Eastham

11:45AM *A Novel Simplified Structure for Single-Drive Bearingless Motor*  
Hiroya Sugimoto, Itsuki Shimura and Akira Chiba

Noise and Vibration Issues in Electric Machines, Chair: Junichi Itoh, Ali Bazzi, Room: 102B 205

10:30AM *Stator Vibration and Acoustic Noise Analysis of FSPM for a Low-Noise Design*  
Chandan Sikder and Iqbal Husain

10:55AM *Current Waveform for Noise Reduction of Switched Reluctance Motor in Magnetically Saturated Condition*  
Jihad Furqani, Masachika Kawa, Kyohei Kiyota and Akira Chiba

11:20AM *Torque Ripple Reduction Techniques for Stator DC Winding Excited Vernier Reluctance Machines*  
Mengxuan Lin, Ronghai Qu, Jian Li, Shaofeng Jia and Yang Lu

11:45AM *On the cross coupling effects in structural response of Switched Reluctance Motor Drives*  
Shiliang Wang, Lei Gu, Babak Fahimi and Mehdi Moallem

Electrical Drives for Aerospace and Traction Applications, Chair: Gianmario Pellegrino, Davide Barater, Room: 101CD 206

10:30AM *Asymmetrical Twelve-Phase Induction Starter/Generator for More Electric Engine in Aircraft*  
Radu Bojoi, Sandro Rubino, Andrea Cavagnino and Silvio Vaschetto

10:55AM *Axial Position Estimation of Conical Shaped Motor for Green Taxiing Application*  
Sara Roggia, Francesco Cupertino, Michael Galea and Chris Gerada

11:20AM *Closed-form approach for predicting overvoltage transients in cable-fed PWM motor drives for MEA*  
Giorgio Pietrini, Davide Barater, Carlo Concari, Michael Galea and Chris Gerada

11:45AM *An open problem for More Electrical Aircraft (MEA): how insulation systems of actuators can be qualified?*  
Giorgio Pietrini, Davide Barater, Giovanni Franceschini, Paolo Mancinelli and Andrea Cavallini

Magnetics II , Chair: Shuo Wang, Gerard Hurley, Room: 102A 207

10:30AM *High Power Density Impedance Control Network DC-DC Converter Utilizing an Integrated Magnetic Structure*  
Ashish Kumar, Jie Lu, Saad Pervaiz, Alihossein Sepahvand and Khurram Afridi

10:55AM *Time-Domain Homogenization of Litz-Wire Bundles in FE Calculations*  
Korawich Niyomsatian, Jeroen Van den Keybus, Ruth Sabariego and Johan Gyselinck

11:20AM *High Frequency Core Coefficient for Transformer Size Selection*  
Lukas Mueller and Jonathan Kimball

11:45AM *Very High Frequency Integrated Voltage Regulator for Small Portable Devices*  
Dongbin Hou, Fred Lee and Qiang Li

Device Short Circuit Capability, Chair: Yi Deng, Ty McNutt, Room: 202C 207

10:30AM *Robustness in Short-Circuit Mode: Benchmarking of 600V GaN HEMTs with Power Si and SiC MOSFETs*  
Nasser Badawi, Abdullah Eial Awwad and Sibylle Dieckerhoff

10:55AM *Investigation on the Short Circuit Safe Operation Area of SiC MOSFET Power Modules*  
Paula Diaz Reigosa, Francesco Iannuzzo, Haoze Luo and Frede Blaabjerg

11:20AM *Short-Circuit Protection of 1200V SiC MOSFET T-type Module in PV Inverter Application*  
Yuxiang Shi, Ren Xie, Lu Wang, Yanjun Shi and Hui Li

11:45AM *Prediction of Short-Circuit-Related Thermal Stress in Aged IGBT Modules*  
Amir Sajjad Bahman, Francesco Iannuzzo, Christian Uhrenfeldt, Frede Blaabjerg and Stig Munk-Nielsen

Thursday, September 22, 2:00PM-3:40PM

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2:00PM *Flexible PCC Voltage Unbalance Compensation Strategy for Autonomous Operation of Parallel DFIGs*  
Tao Wang and Heng Nian

2:25PM *Analysis and Comparison of Super- Synchronous Resonance in Small and Large Scale DFIG System*  
Yipeng Song, Frede Blaabjerg and Xiongfei Wang

2:50PM *A Super-synchronous Doubly Fed Induction Generator Option for Wind Turbine Applications*  
Kee Shin and Thomas Lipo

3:15PM *Fault Diagnosis of Wind Turbine Gearbox Using DFIG Stator Current Analysis*  
Fangzhou Cheng, Chun Wei, Liyan Qu and Wei Qiao

Utility Scale Battery Systems, Chair: Daniel-Ioan Stroe, Frede Blaabjerg, Room: 203C 209

2:00PM *Controller for Combined Peak-Load Shaving and Capacity Firming Utilizing Multiple Energy Storage Units in a Microgrid*  
Andrew Hintz, Kaushik Rajashekara and Prasanna Rajagopal

2:25PM *Energy Storage Configuration Strategy for Virtual Synchronous Machine*  
Chang Yuan, Chang Liu, Tianyang Zhao, Niang Tang and Xiangning Xiao

2:50PM *Control of Energy Storage System integrating electrochemical batteries and SC for grid-connected applications*  
Ruben Capo-Misut, Raul Santiago Munoz-Aguilar, Joan Rocabert, Jose Ignacio Candela and Pedro Rodriguez

3:15PM *A Novel Approach towards Energy Storage System Sizing Considering Battery Degradation*  
Yuhua Du, Rishabh Jain and Srdjan M. Lukic

AC Microgrids III: Operation, Control and Energy Management, Chair: Juan Carlos Vasquez, Juan Manuel Guerrero, Room: 203DE 209

2:00PM *Robust Decentralized Voltage and Frequency Control of Generators in Islanded Microgrids Using $$-Synthesis*  
Mohsen Azizi and Sayed Ali Khajehoddin

2:25PM *Thyristor Based Short Circuit Current Injection in Isolated Grids*  
Bjarte Hoff, Pawan Sharma and Trond Ostrem

2:50PM *Optimized Energy Management System to Reduce Fuel Consumption in Remote Military Microgrids*  
Norma Anglani, Michele Colombini and Giovanna Oriti

3:15PM *Analysis and Improvement of the Energy Management of an Isolated Microgrid in Lencois Island based on a Linear Optimization Approach*  
Federico de Bosio, Adriana Carolina Luna, Luiz Antonio de Souza Ribeiro, Moises Graells, Osvaldo Ronald Saavedra and Josep Maria Guerrero

Battery Charging for Transportation Electrification, Chair: Theodore Bohn, Alireza Khaligh, Room: 102D 210

2:00PM *A Primary Full-Integrated Active Filter Auxiliary Power Module in Electrified Vehicle Applications with Single-Phase Onboard Chargers*  
Ruoyu Hou and Ali Emadi

2:25PM *Sensitivity Analysis of a Wireless Power Transfer (WPT) System for Electric Vehicle Application*  
Madhu sudhan Chinthavali and Zhiqiang Wang

2:50PM *Design of a Dual-Loop Controller for In-motion Wireless Charging of an Electric Bus*  
Reza Tavakoli, Aleksandar Jovicic, Niranjan Chandrappa, Ryan Bohm and Zeljko Pantic

3:15PM *Design of CRM AC/DC Converter for Very High-Frequency High-Density WBG-Based 6.6kW Bidirectional On-Board Battery Charger*  
Zhengyang Liu, Bin Li, Fred Lee and Qiang Li

Three-Phase Inverter PWM, Chair: Subhashish Bhattacharya, Giacomo Scelba, Room: 202A 211

2:00PM *SiC MOSFET Zero-Voltage-Switching SVM controlled Three-phase Grid Inverter*  
Ning He, Yawen Li, Chengrui Du, Chao Liu, Changsheng Hu and Dehong Xu

2:25PM *A Novel Soft-switching Modulation Scheme for Isolated DC-to-three-phase-AC Matrix-based Converter Using SiC Device*  
Xiaohang Yu, Fanning Jin and Mengqi Wang

2:50PM *New PWM Technique for Grid-Tie Isolated Bidirectional DC-AC Inverter Based High Frequency Transformer*  
Mahmoud Sayed, Suzuki Kazuma, Takeshita Takaharu and Kitagawa Wataru

3:15PM *Reduction of Input Current Harmonics based on Space Vector Modulation for Three-phase VSI with varied Power Factor*  
Koroku Nishizawa, Jun-ichi Itoh, Akihiro Odaka, Akio Toba and Hidetoshi Umida

AC-AC Converters II, Chair: Luca Zarri, Matthias Preindl, Room: 202E 211

2:00PM *A Comparison of Indirect Matrix Converter Based Open-End Winding Drives Against State-of-the-Art*  
Saurabh Tewari and Ned Mohan

2:25PM *Common Mode Voltage Reduction in Open-End Multi-phase Load System fed Through Matrix Converter*  
Khaliqur Rahman, Atif Iqbal, Nasser A. Al-Emadi, Rashid M Alammari, Lazhar Ben Brahim and Hossein Dehghani Tafti

2:50PM *Experimental Comparison of Devices Thermal Cycling in Direct Matrix Converters (DMC) and Indirect Matrix Converters (IMC) using SiC MOSFETs*  
Andrew Trentin, Liliana de Lillo, Lee Empringham, Pericle Zanchetta, Pat Wheeler and Jon Clare

3:15PM *A Carrier-based Modulation Strategy for Multi-modular Matrix Converters with Zero Common-mode Voltage*  
Wenjing Xiong, Yao Sun, Mei Su, Jian Yang and Chunsheng Wang

Modular Multilevel Converters (MMC) III, Chair: Di Zhang, Jiangchao Qin, Room: 202B 212

2:00PM *Design and Implementation of Finite State Machine Decoders for Phase Disposition Pulse Width Modulation of Modular Multilevel Converters*  
Carlos Teixeira, Yichao Sun, Grahame Holmes and Brendan McGrath

2:25PM *Control of the AC-AC Modular Multilevel Converter under Submodule Failure*  
Yang Qichen and Saeedifard Maryam

2:50PM *Control of a Modular Multilevel Converter with Pulsed DC Load*  
Marija Jankovic, Alan Watson, Alessandro Costabeber and Jon Clare

3:15PM *Short circuit output protection of MMC in Voltage Source Control Mode*  
Manfred Winkelnkemper, Lukas Schwager, Pawel Blaszczyk, Mischa Steurer and Dionne Soto

DC-DC: Isolated Convertes, Chair: Sudip Mazumder, Jason Stauth, Room: 102C 213

2:00PM *An Isolated Three-Port DC-DC Converter with High Power Density in 10 cm X 5 cm X 0.8 cm Card Size for Flexible Automotive Systems*  
Shuntaro Inoue, Kenichi Itoh, Masanori Ishigaki, Takahide Sugiyama and Masaru Sugai

2:25PM *Auxiliary power supply based on a modular ISOP Flyback configuration with very high input voltage*  
Alberto Rodriguez, Maria R. Rogina, Mariam Saeed, Diego G. Lamar, Manuel Arias, Mario Lopez and Fernando Briz

2:50PM *Design Considerations for Series Resonant Converters with Constant Current Input*  
Hongjie Wang, Tarak Saha and Regan Zane

3:15PM *Galvanically Isolated Switched-Boost-Based DC-DC Converter*  
Saman A. Gorji, Mehran Ektesabi, Trung N. Nguyen and Jinchuan Zheng

Modeling and Control of DC-AC converters II, Chair: Thomas Jahns, Jon Are Suul, Room: 202D 213

2:00PM *A Triangle Phase-Shift Control Strategy for Interleaved Critical-Mode Power Converters*  
Lanhua Zhang, Rachael Born, Qingqing Ma, Yu Wei, Xiaonan Zhao and Jih-Sheng Lai

2:25PM *Seamless Transition Control between Motoring and Generating Modes of a Bidirectional Multi-Port Power Converter Used in Automotive SRM Drive*  
Fan Yi, Wen Cai and Babak Fahimi

2:50PM *Three-Phase Inverter Modeling using Multifrequency Averaging with Third Harmonic Injection*  
Xiao Liu and Aaron Cramer

3:15PM *Transformation Based Tracking Controller for a GaN Microinverter*  
Ankit Gupta, Harshit Soni, Sudip Mazumder, Shirish Raizada, Debanjan Chatterjee, Paromita Mazumder and Parijat Bhattacharjee

Stability in Power Converters II, Chair: Dusan Borojevic, Leila Parsa, Room: 102E 214

2:00PM *Source-side Series-virtual-impedance Control Strategy to Stabilize the Cascaded System with Improved Performance*  
Xin Zhang, Qing-Chang Zhong and Wen-Long Ming

2:25PM *Bifurcation Analysis of Photovoltaic-Battery Hybrid Power System with Constant Power Load*  
Meng Huang, Lijun Wei, Yi Liu, Jianjun Sun and Xiaoming Zha

2:50PM *Measurement technique to determine the impedance of automotive energy nets for stability analysis purpose based on a floating capacitor H-bridge converter*  
Matthias Hiermeier, Michael Muerken, Thomas Hackner and Johannes Pforr

3:15PM *Harmonic Suppression and Stability Improvement for Aggregated Current-Controlled Inverters*  
Qiang Qian, Shaojun Xie, Jinming Xu and Lin Ji

Design Optimization of Power Converters, Chair: Suman Debnath, Pericle Zanchetta, Room: 202C 215

2:00PM *Efficiency-wise Optimal Design Methodology of LCLC Converter for Wide Input Voltage Range Applications*  
Yang Chen, Hongliang Wang, Zhiyuan Hu, Yan-fei Liu, Jahangir Afsharian and Zhihua (Alex) Yang

2:25PM *Reliability-Oriented Design of LC Filter in Buck DC-DC Converter with Multi-Objective Optimization*  
Yi Liu, Meng Huang, Yuexia Liu and Xiaoming Zha

2:50PM *Optimal Design of Output LC Filter and Cooling for Three-Phase Voltage-Source Inverters Using Teaching-Learning-Based Optimization*  
Hamzeh Jamal, Saher Albatran and Issam Smadi

3:15PM *Using design by optimization for reducing the weight of a SiC switching cell*  
Mylene Delhommais, Gnimdu Dadanema, Yvan Avenas, Jean-Luc Schanen, Francois Costa and Christian Vollaire

Active Power Filters, Chair: Luis Moran, Andy Knight, Room: 101B 216

2:00PM *Multilevel Nine-Leg Converter Universal Active Power Filter*  
Phelipe Leal Serafim Rodrigues, Cursino Brandao Jacobina and Mauricio Beltrao de Rossiter Correa

2:25PM *Central Control and Distributed Protection of the DSBC and DSCC Modular Multilevel Converters*  
Andre Hillers, Hao Tu and Juergen Biela

2:50PM *Mitigating the Effect of Series Capacitance Unbalance on the Voltage Reduction Capability of an Auxiliary CSI used as Switching Ripple Active Filter*  
Savvas Papadopoulos, Mohamed Rashed, Christian Klumpner and Pat Wheeler

3:15PM *A New Control Method of Suppressing DC-Capacitor Voltage Ripples Caused by Third-Order Harmonic Compensation in Three-Phase Active Power Filters*  
Tomoyuki Mannen, Issei Fukasawa and Hideaki Fujita

Non-Conventional Machine Configurations II, Chair: Guan-Ren Chen, Nicola Bianchi, Room: 101A 216

2:00PM *Design of Dual Purpose No Voltage Combined Windings for Bearingless Motors*  
Eric Severson, Robert Nilssen, Tore Undeland and Ned Mohan

2:25PM *Synchronous Generator Field Excitation Via Capacitive Coupling Through a Journal Bearing*  
Jiejian Dai Dai, Skyler Hagen, Daniel Ludois and Ian Brown

2:50PM *Development of Stator-Magnetless Linear Synchronous Motor for Sensorless Control*  
Makino Shogo, Kakihara Masanobu, Takase Yoshiyasu, Takaki Mamoru, Shikayama Toru, Ohto Motomichi, Higuchi Tsuyoshi and Abe Takashi

3:15PM *Ultralightweight Motor Design Using Electromagnetic Resonance Coupling*  
Kazuto Sakai and Yuta Sugasawa

Magnetic Gears, Chair: Siavash Pakdelian, Kan Akatsu, Room: 102B 217

2:00PM *A Novel Reluctance Magnetic Gear for High Speed Motor*  
Kohei Aiso and Kan Akatsu

2:25PM *Analysis of a Magnetically Geared Lead Screw*  
Mojtaba Bahrami Kouhshahi and Jonathan Bird

2:50PM *Design Comparison of NdFeB and Ferrite Radial Flux Magnetic Gears*  
Matthew Johnson, Matthew C. Gardner and Hamid A. Toliyat

3:15PM *Power Transferring of Magnetic-Geared Permanent Magnet Machines*  
Leilei Wu, Ronghai Qu, Dawei Li and Yuting Gao

High Speed and Direct Drives, Chair: Mazharul Chowdhury, Rukmi Dutta, Room: 101CD 218

2:00PM *Robust Control of an Open-Ended Induction Motor Drive With a Floating Capacitor Bridge over a Wide Speed Range*  
Michele Mengoni, Albino Amerise, Luca Zarri, Angelo Tani, Giovanni Serra and Domenico Casadei

2:25PM *High speed operation of permanent magnet machine position sensorless drive using discretized EMF estimator*  
Shih-Chin Yang and Guan-Ren Chen

2:50PM *DC Voltage Regulated PWM Inverter for High-Speed Electrical Drives*  
Vito Giuseppe Monopoli, Maria Concetta Poliseno, Maria Chiara Stomati and Francesco Cupertino

3:15PM *Variable Time Step Control with Synchronous PWM in Low Frequency Modulation Index for AC Machine Drive*  
Sungho Jung, Jaeyong Park, Euihoon Chung and Jung-Ik Ha

Power Assemblies , Chair: Jelena Popovic, Yvan Avenas, Room: 102A 218

2:00PM *Implementation and Performance of a Current Sensor for Laminated Bus Bar*  
Yoshikazu Kuwabara, Keiji Wada, Jean-Michel Guichon, Jean-Luc Schanen and James Roudet

2:25PM *Busbar Design for SiC-Based H-Bridge PEBB using 1.7 kV, 400 A SiC MOSFETs Operating at 100 kHz*  
Niloofar Rashidi Mehrabadi, Igor Cvetkovic, Jun Wang, Rolando Burgos and Dushan Boroyevich

2:50PM *Ultra-low Inductance Design for a GaN HEMT Based 3L-ANPC Inverter*  
Emre Gurpinar, Francesco Iannuzzo, Yongheng Yang, Alberto Castellazzi and Frede Blaabjerg

3:15PM *Layout Study of Contactless Magnetoresistor Current Sensor for High Frequency Converters*  
Mehrdad Biglarbegian, Shahriar Jalal Nibir, Hamidreza Jafarian, Johan Enslin and Babak Parkhideh

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DETAILED PROGRAM

Monday, September 19, 1:30PM-4:00PM

Modular Multi-Level Converters, HVDC, and DC Grids I

Monday, September 19, 1:30PM-4:00PM, Room: 203DE, Chair: Enrico Santi, Ghanshyamsinh Gohil

**1:30PM***The Modular Embedded Multilevel Converter: A Voltage Source Converter with IGBTs and Thyristors [#143]*  
Di Zhang, Rajib Datta, Andrew Rockhill, Qin Lei and Luis Garces   
, GE, United States; Eaton, United States; ASU, United States

This paper presents a new converter topology for voltage source converter based high voltage dc application, named modular embedded multilevel converter (MEMC). MEMC is based on a three level structure and consists of series- connected IGBT bridge stacks, like the popular modular multilevel converter (MMC) and series-connected thyristor stacks. The IGBT bridge stacks are leveraged to generate the output the voltage waveforms and to commute the thyristors. The basic operation principle and the methods to commutate the thyristors are explained in detail. Due to the three level structure, the total number of IGBT stacks are reduced by half compared with MMC, leading to much lower energy storage, weight, volume and system complexity. Also by replacing part of the IGBT stack in MMC with thyristor stack, both of the system conduction loss and switching loss can be further reduced. The simulation results proved the analysis and verified the feasibility and benefits of the proposed converter topology.

**1:55PM***Multi-Module-Cascade High-Voltage Composite Switch [#171]*  
Binbin Wang, Yao Lu, Xinnian Sun, Wenxi Yao and Zhengyu Lu   
, Zhejiang University, China; Hangzhou D-River Electric Technology Company, China; Hangzhou Silver Lake Electric Equipment Company, China

Application of low-voltage insulated gate bipolar transistors (IGBTs) in high voltage power electronics system is attractive for low cost, high operating frequency, low weight and low volume. The paper presents a multi-module- cascade High-Voltage Switch based on modular multilevel converter (MMC). With the cascade of low-voltage modules, it is realized high-voltage composite switches with working voltages of several kilovolts. The switch proposed can absorb voltage spikes caused by parasitic parameters and back energy stored in parasitic parameters to power supply. The voltage balancing is automatic during conduction mode. The voltage-balancing scheme during static and dynamic transient state is explained and analyzed in detail. The simulation results are presented to verify the validity of the scheme.

**2:20PM***Step-Up MMC with Staircase Modulation: Analysis, Control, and Switching Strategy [#1002]*  
Younes Sangsefidi and Ali Mehrizi-Sani   
, Washington State University, United States

Modular multilevel converters (MMC) provide a low-harmonic output voltage without needing several isolated power sources. This multilevel converter can use either half-bridge or full- bridge submodules with PWM or staircase modulation techniques. This paper analyzes the full- bridge MMC, which is called step-up MMC because of its boosting capability, using the staircase modulation. Different operational modes of the step-up MMC are studied, and a generalized control and switching algorithm is proposed. This algorithm ensures the capacitor charge balance while providing the required high-quality output voltage. Compared to a half- bridge MMC with a similar investment in capacitor and switches, the step-up MMC shows a superior performance as it has 1) low total harmonic distortion (THD) of the output waveform, 2) high output voltage with a low input DC voltage, and 3) the possibility to provide different achievable output voltages using submodules with negative voltage at their terminals. The performance of the proposed step-up MMC with staircase modulation and presented theories are validated by simulation case studies.

**2:45PM***A High Step-Up Ratio Soft-Switching DC-DC Converter for Interconnection of MVDC and HVDC Grids [#1208]*  
Shenghui Cui, Nils Soltau and Rik W. De Doncker   
, RWTH Aachen University, Germany

DC grid technology is regarded as a promising solution for future electric networks integrating a great amount of renewable energies. It calls for high efficiency dc-dc converters with high step-up ratio to interconnect medium voltage (MV) dc distribution grids and high voltage (HV) dc transmission grids. This paper presents an isolated soft-switching dc-dc converter combining two-level converters in parallel on MV side and a modular multilevel converter (MMC) on HV side. Moreover, a comprehensive control method of the proposed converter is presented. By the proposed method, a certain reactive current is injected into the MV side by the MMC to ensure soft-switching on MV side. The proposed converter presents low semiconductor losses over a wide power range at variable input/output voltages. Simulations of a 50 kV/400 kV, 400 MW system are conducted to evaluate semiconductor losses and verify the validity of this work.

**3:10PM***Fault Tolerant Cell Design for MMC-based Multiport Power Converters [#1672]*  
Alberto Zapico, Mario Lopez, Alberto Rodriguez and Fernando Briz   
, University of Oviedo, Spain

The Modular Multilevel Converter (MMC) is a promising technology for medium-high voltage DC/AC convert- ers, being adequate for HVDC transmission systems. Among the appealing characteristics of the MMC are their modularity, and consequently their scalability, as well as the fact that there is no bulk storage element. One key aspect for the operation of the MMC is the response in the event of a short circuit in the DC link. Conventional MMC cells consist of a half-bridge and a capacitor, and have no capability to block the short circuit in the DC side, meaning that expensive and bulky circuit breakers might be needed in this case. Several fault tolerant cell designs have been proposed. However, these desings always bring an increase in the number of power devices and losses. Conventional MMC design can be enhanced to provide added functionalities, e.g. multiport power converters and solid state transformers (SST). A mean to achieve this is by providing the cells the capability to transfer power. This enhancements will imply an increase in the number of power devices and passives, as well as further complexity of the control. However, the resulting cells structures can offer new opportunities regarding fault tolerance. This paper revises the fault tolerance capability of MMCs, and analyzes the behavior of MMC-based multiport power converters in the event of faults. A new cell structure will be proposed capable of blocking the DC short circuit current, therefore protecting the power converter with reduced extra elements.

**3:35PM***HIL Platform Design and Controller Verification for MMC Based HVDC Networks [#1244]*  
Luis Herrera, Xiu Yao and Jin Wang   
, University of Dayton Research Institute, United States; University at Buffalo, United States; The Ohio State University, United States

High Voltage DC systems are gaining widespread attention due to the advances in power electronic devices and converters. MMCs are very popular nowadays in this type of application. This paper first revisits the dynamic equations of the circulating current of a MMC to incorporate a disturbance term. Based on the modified equations, a disturbance rejection controller is proposed to eliminate the double fundamental ac part of this current. In a larger scale, a platform for the offline and real time simulation of MMC based HVDC is designed. Hardware-in-the Loop (HIL) simulations are then conducted to validate the circulating current controller and a case study on the Lower Churchill project is illustrated to show the feasibility of an actual MMC implementation.

Renewable Energy I

Monday, September 19, 1:30PM-4:00PM, Room: 203C, Chair: Wei Qiao, Liyan Qu

**1:30PM***Energy Storage Opportunities and Capabilities in a Type 3 Wind Turbine Generator [#152]*  
Eduard Muljadi, Vahan Gevorgian and Anderson Hoke   
, National Renewable Energy Laboratory, United States

Wind power plants and other renewable power plants with power electronic interfaces are capable of delivering frequency response (both governor and/or inertial response) to the grid by a control action; thus, the reduction of available online inertia as conventional power plants are retired can be compensated by designing renewable power plant controls to include frequency response. The source of energy to be delivered as inertial response is determined by the type of generation and control strategy chosen. The cost of energy storage drops over time, and global research activities on energy storage are very active, funded both by the private industry and governments. Different industry sectors (e.g., transportation, energy) are the major drivers of the recent storage research and development. This work investigates the opportunities and capabilities of deploying energy storage in renewable power plants. In particular, we focus on wind power plants with doubly-fed induction generators, or Type 3 wind turbine generator (WTGs). We find that the total output power of a system with Type 3 WTGs with energy storage can deliver a power boost during inertial response that is up to 45% higher than one without energy storage without affecting the torque limit, thus enabling an effective delivery of ancillary services to the grid.

**1:55PM***Assessment of System Frequency Support Effect of a PMSG-WTG Using Torque-Limit Based Inertial Control [#281]*  
Xiao Wang, Wenzhong Gao, Jianhui Wang, Ziping Wu, Weihang Yan, Vahan Gevorgian, Yingchen Zhang, Eduard Muljadi, Moses Kang, Min Hwang and Yong Cheol Kang   
, University of Denver, Northeastern Univ., United States; University of Denver, United States; Northeastern Univ., China; National Renewable Energy Laboratory, United States; Chonbuk National Univ., Korea (South)

The presented method aims to improve the frequency support capability considering the maximum torque restriction of a permanent magnet synchronous generator. The advantages of the proposed method are improved frequency nadir in the event of an under-frequency disturbance; and avoidance of over- deceleration and a second frequency dip during the inertial response. The system frequency response is different, with different slope values in the power-speed plane when the inertial response is performed. The proposed method is evaluated in a modified three-machine, nine-bus system. The simulation results show that there is a trade-off between the recovery time and FN, such that a gradual slope tends to improve the FN and restrict the rate of change of frequency aggressively while causing an extension of the recovery time. These results provide insight into how to properly design such kinds of inertial control strategies for practical applications.

**2:20PM***Improved Efficiency of Local EPS through Variable Switching Frequency Control of Distributed Resources [#1128]*  
Jose M. Cano, Andres Suarez, Angel Navarro-Rodriguez and Pablo Garcia   
, University of Oviedo, Spain

This contribution explores the possibility of improving the global efficiency of three-phase inverter-based distributed resources (DR) embedded in low- voltage (LV) distribution feeders, by the adaptation of their switching frequency (SF) to the operation point of both the converter and local loads. The core of this proposal lies on the fact that in a good number of applications, in both services and residential sectors, the owner of the DR is also in charge of the losses caused in the local electric power system (EPS). This fact leaves room for a global optimization of the power losses, i.e, converter losses will be considered together with those losses caused by the current harmonics injected into the local grid. A dynamic adaptive SF frame of the DR is considered in this proposal to allow its operation beyond its rated frequency at light loads, subjected to the thermal constraints of the device. Simulation results obtained using PLECS software as well as an experimental validation of the method are included.

**2:45PM***Smart EV Charging System for Maximising Power Delivery from Renewable Sources [#1207]*  
Fearghal Kineavy and Maeve Duffy   
, NUI Galway, Ireland

The design of a smart EV charging system that provides maximum power delivery from renewable energy (PV) sources is described, through the application of control strategies which ensure that system power converters are operated in regions of high efficiency. Using the proposed approach, system level models predict power efficiency improvements of up to 6% for a 6.5 kW PV installation with four EV charging points. The implementation of a complete small-scale demonstrator system designed as a test bed for validation and investigation of other smart control algorithms is described, including a PV source, power converters, a smart controller and Li-ion battery loads.

**3:10PM***Instantaneous Frequency Regulation of Microgrids via Power Shedding of Smart Load and Power Limiting of Renewable Generation [#1284]*  
Shuo Yan, Ming Hao Wang, Tian Bo Yang and S. Y. Ron Hui   
, The University of Hong Kong, Hong Kong

In this paper, a collaborative control scheme is proposed to improve the stability of the microgrid with intermittent renewable energy sources. Different from other cooperative control schemes targeting mostly on regulating the generation side, the proposed operating scheme utilizes all controllable resources in the microgrid, including renewable energy sources (RESs), storage devices, and controllable loads. A modified maximum power point tracking (MPPT) scheme is proposed for RESs in limiting its power output when frequency surges over its upper limit. The adaptive/smart load enabled by the electric spring (ES) reduces the power demand when the frequency falls below the lower limit. Both operating schemes for RES and adaptive/smart load can be activated when the storage system fails to respond to disturbances. The proposed collaborative scheme can be enacted in an instantaneous manner and is easy to implement by simply modifying the control of RES and adaptive/smart load. Simulation results have confirmed that the proposed scheme is efficient in reducing the frequency oscillation in a microgrid.

**3:35PM***Modeling and identification of harmonic instability problems in wind farms [#1039]*  
Esmaeil Ebrahimzadeh, Frede Blaabjerg, Xiongfei Wang and Claus Leth Bak   
, Aalborg University, Denmark

In power electronics based power systems like wind farms, the interactions between the inner control systems of the power converters and the passive components may lead to high frequency oscillations, which can be called harmonic instability. In this paper, a simple methodology is presented to identify harmonic instability problems in wind farms, where many wind turbines, cables, transformers, capacitor banks, shunt reactors, etc, typically are located. This methodology introduces the wind farm as a Multi-Input Multi-Output (MIMO) control system, where the linearized models of fast inner control loops of the grid-side converters are considered. Therefore, instability problems of the whole wind farm are predicted based on the poles of the introduced MIMO system. In order to confirm the effectiveness of the proposed analytical approach, time- domain simulations are performed in the PSCAD/EMTDC software environment for a 400-MW wind farm. The proposed analytical analysis method and time-domain simulation results show that both dynamics of the power electronic converter and the parameters of the passive component can effect on the wind farm stability.

Modelling, Analysis, and Control of Grid-Connected Converters

Monday, September 19, 1:30PM-4:00PM, Room: 202A, Chair: Behrooz Mirafzal, Fariba Fateh

**1:30PM***A Method for Improving Stability of LCL-Type Grid-Tied Inverters in Weak Grid with Resonant Feed forward Control [#186]*  
Yu Tang, Liuliu Huang and Guoshu Zhao   
, NUAA, China; Jinling Institute of Technology, China

Weak grid is commonly seen as a voltage source which contains the gird impedance and background harmonics. The grid current closed-loop control and the grid voltage feed forward control are coupled with each other because of the grid impedance. The proportion feed forward control strategy introduces a positive feedback loop, which affects the grid current quality and the system stability. This paper establishes the model of LCL-type grid-tied inverter, and elaborates the formation mechanism of resonant current under weak grid condition. The resonant feed forward control (RFC) is proposed to attenuate the response of grid impedance during the resonant frequency band, and also to improve the phase margin and decrease the injected current steady state error. A 3kW single-phase grid-tied inverter prototype is designed in the lab, and the proposed RFC strategy is verified by experiments.

**1:55PM***Passivity Enhancement in RES Based Power Plant with Paralleled Grid-Connected Inverters [#621]*  
Haofeng Bai, Xiongfei Wang and Frede Blaabjerg   
, Aalborg University, Denmark

Harmonic instability is threatening the operation of power plants with multiple grid connected converters in parallel. To analyze and improve the stability of the grid connected converters, the passivity of the output admittance converters is first analyzed in this paper. It is shown that the non-passivity of the output admittance of the converters will make the system un-stable under certain grid conditions. Based on the stability analysis, this paper proposes a new method to cancel the non-passivity of the power plant by using inverters with different power rating and control strategies. Three specific cases, where the LCL parameters, sampling frequency and current control strategies of the paralleled inverters are different, are studied. The results suggest that the grid connected converters with different power ratings and control strategies improve the stability of the power plant as a whole.

**2:20PM***Voltage Stability Analysis Using A Complete Model of Grid-Connected Voltage-Source Converters [#653]*  
Zhi-Xiang Zou, Andreas Martin Kettner, Giampaolo Buticchi, Marco Liserre and Mario Paolone   
, University of Kiel, Germany; Ecole polytechnique federale de Lausanne, Switzerland

Due to the increasing popularity of renewable energies, a significant share of the power generation in future microgrids is expected to originate from converter-interfaced Distributed Energy Resources (DERs). Traditionally, idealized device models are used to conduct grid stability studies. For instance, a DER interfaced via a Voltage-Source Converter (VSC) would be modeled as an ideal current or power source (depending on the control schemes), ignoring non-ideal behavior like the response of the converter synchronization. However, such a simplification may lead to misjudging the stability, in particular for weak microgrids. To address this issue, ZIP models of grid-interfaced VSCs, which take into account both the control scheme and the synchronization, are developed in this paper. The influence of the synchronization response on the stability of a weak microgrid system is demonstrated using a benchmark system simulated in MATLAB/Simulink. It is shown that the idealized models normally used for static stability analysis do underestimate the voltage stability issue in the investigated microgrid system.

**2:45PM***Resonant Control for Power Converters Connected to Weak and Micro Grid Systems with Variant Frequency [#701]*  
Jaime Rohten, Pedro Melin, Jose Espinoza, Daniel Sbarbaro, Jose Silva and Marcelo Perez   
, Bio Bio University, Chile; Concepcion University, Chile; Santa Maria University, Chile

Controlled Power Converters are extensively used in industrial applications as they can adapt the electrical energy as required by the application. However, these devices must be properly commutated in order to control voltages and currents. Indeed, power converters are known to be multivariable, coupled, and nonlinear systems; therefore, the control technique needs to be chosen carefully. There are several control techniques reported in the literature for power converters and one of them is the Resonant Control (RC) mainly used on ac based systems. Advantageously, RC guarantees zero steady state error for a sinusoidal reference with a constant frequency and, in addition, it does not need a stationary to rotating reference frame transformation. However, the conventional RC approach requires the exact ac mains frequency value to ensure zero steady state error, being a significant drawback for applications where variable frequency environments are expected. This paper proposes an enhanced RC scheme capable to work under variable frequency scenarios, as in weak and micro grid systems while guaranteeing zero steady state error. The scheme results in a simple algorithm based upon discrete mathematics whose parameters become independent of the ac grid frequency. Results show the feasibility of the proposed approach even under severe ac frequency variations (over 100%) while featuring a stable control loop operation and zero steady state error.

**3:10PM***Extended-Horizon Finite-Control-Set Predictive Control of a Multilevel Inverter for Grid-Tie Photovoltaic Systems [#702]*  
Jose Silva, Jose Espinoza, Jaime Rohten, Luis Moran, Eduardo Espinosa, Carlos Baier and Javier Munoz   
, Concepcion University, Chile; Catholic University, Chile; Talca University, Chile

This paper proposes a control scheme composed by a linear control and a predictive algorithm with extended horizon for a three-level neutral-point-clamped (NPC) inverter topology for grid- tie photovoltaic applications. The proposed strategy is capable to balance the capacitor voltages at the DC link and to generate a sinusoidal current at the grid side with a unitary power factor. Differently to other approaches, the proposed scheme is easy to digitally implement, and does not need to retune the controller cost function weighting parameters, and reduces the computational effort. These advantages are added to the capability to operate photovoltaic modules at the maximum power point (MPP). Results validate the proposed control methods and the mathematical analysis

**3:35PM***A Novel Seamless Transfer Control Strategy For Wide Range Load [#406]*  
Kiryong Kim, Dongsul Shin, Jong-Pil Lee, Tae-Jin Kim, Dong-wook Yoo and Heeje Kim   
, Pusan National University, Korea, Republic of; LG Electronics, Korea, Republic of; Korea Electrotechnology Research Institute, Korea, Republic of

This paper proposes a novel seamless transfer control strategy of three-phase grid-connected inverter between grid-connected (GC) and stand-alone (SA) modes w which can cover from no load to full load, even in non linear (NL) loads. The three-phase grid-connected inverter which uses in distributed generation (DG) s system can be operated in both GC and SA control modes, especially for energy s storage systems. The current and the voltage is controlled by the inverter in G GC and SA mode respectively. In other words, the control methods are d differently applied to each mode. When the grid outage, the inverter changes its operation mode. During the mode transition from GC to SA, undesired phenomena such as a voltage spike and a current spike are occurred. With the proposed method, the seamless transfer can be achieved. In addition, proposed algorithm is considered the non detection zone (NDZ) condition which the inverter cannot recognize changes such as magnitude and frequency variation of critical load. The proposed control method is verified by the experimental results.

DC-DC Converters: Switched Capacitor

Monday, September 19, 1:30PM-4:00PM, Room: 102D, Chair: Alireza Khaligh, Nasser Badawi

**1:30PM***Hybrid Switched-Capacitor Quadratic Boost Converters with Very High DC Gain and Low Voltage Stress On Their Semiconductor Devices [#21]*  
Manxin Chen, Jiefeng Hu, Li Kerui and Adrian Ioinovici   
, Sun Yat-sen University, China; Holon Institute of Technology, Israel

By inserting a simple cell formed by a capacitor and diode into quadratic boost structures, new converters are obtained. They feature: a larger dc gain compared with that of quadratic boost converters and a smaller voltage stress on the switch and output diode, non-pulsating input current, as required for the use in conjunction with the environmental-friendly energy cells, easiness of the transistor driving, line-to-load common ground. The proposed cell can be easily generalized for enhancing the dc gain. The new converters compare favorably with available ones with the same reactive elements count. Simulations and experimental results confirm the theoretical analysis of the proposed converter.

**1:55PM***Mixed Switched-Capacitor Based High Conversion Ratio Converter and Generalization for Renewable Energy Applications [#24]*  
Kerui Li, Manxin Chen, Jiefeng Hu and Adrian Ioinovici   
, Sun Yat-sen University, China; Holon Institute of Technology, Israel

A mixed switched-capacitor cell is proposed by integrating a voltage divider with a voltage multiplier. It is inserted in a boost stage for achieving a converter with high conversion ratio, low voltage stress on switches, non- pulsating input current as required as front-end to electrical grids supplied by renewable energy sources. The generalization of the proposed cell allows to achieve an ultra-high dc conversion ratio. Analysis and experimental data show the superiority of the proposed converter over other hybrid converters with similar complexity: higher dc voltage gain and less voltage stress on the switches.

**2:20PM***A High Step-Up DC-DC Converter with Switched-Capacitor and ZVS Realization [#570]*  
Zhipeng Zheng and Liangzong He   
, Xiamen University, China

As generally acknowledged, the high step-up DC-DC converter is widely used in the sustainable energy system as the front-end stage of the DC-AC converter. Therefore, a novel high step-up DC-DC converter is proposed in this paper. The proposed converter with network of switched-inductor and switched-capacitor can achieve high voltage gain under low duty cycle. Meanwhile, the active switches and diodes suffer from low voltage stress compared with conventional step-up DC-DC converter. More importantly, the presented converter employs an auxiliary resonant circuit to realize zero-voltage switching (ZVS) turn-on and ZVS turn-off for the active switches, resulting in high conversion efficiency. Firstly, the operation principle and steady-state performance are discussed in detail. Then, prototype with power rating of 200W is built to verify the performance of the proposed converter. The maximum efficiency of the prototype can be up to 96.3%, and the experimental results agree with the theoretical analysis and the simulation results well.

**2:45PM***A Flying Capacitor Multilevel Converter with Sampled Valley-Current Detection for Multi-Mode Operation and Capacitor Voltage Balancing [#1338]*  
Jan Rentmeister, Christopher Schaef, Benedict Foo and Jason Stauth   
, Dartmouth College, United States

Multi-level hybrid converters have been shown to be a promising class of DC-DC converters. One member of this class is the Flying Capacitor Multilevel (FCML) Converter, which is explored in this work. The multi-mode approach is discussed as a tool to affect high efficiency and power-density across a wide load range, provide variable regulation, and as a general framework to conceptualize the advantages and opportunities of the approach compared to more traditional DC-DC converters. Sampled valley-current detection is explored as a robust control approach for multi-mode regulation. Furthermore, a theoretical framework is developed to show that flying capacitor voltages can be balanced through valley current balancing. Experimental results from a 4-level FCML converter are presented to verify the findings.

**3:10PM***Resonant Switched Capacitor Stacked Topology Enabling High DC-DC Voltage Conversion Ratios and Efficient Wide Range Regulation [#265]*  
Yongjun Li, Jikang Chen, Mervin John, Ricky Liou and Seth Sanders   
, UC Berkeley, United States; Texas Instrument, United States

This paper presents a stacked-topology resonant switched-capacitor (ResSC) dc-dc converter to achieve a high voltage conversion ratio. The topology can be generalized to any N-to-1 dc-dc conversion application with only a single inductor. Multiphase interleaving can be further employed to improve the ripple cancellation and reduce requirement for bypass capacitors. To enable a wide output range while maintaining high efficiency, a phase shift operation is adopted. The regulation is maintained with frequency modulation. The controller is designed with the aid of current phase compensation in addition to voltage mode control. A prototype of a nominal 4-to-1 two phase interleaved resonant switched capacitor converter has been built and tested. The control and regulation of the output voltage are verified through the experiment. Burst mode is further introduced to improve efficiency at the light load condition.

**3:35PM***Bi-Directional Bridge Modular Switched-Capacitor-Based DC-DC Converter with Phase-Shift Control [#1321]*  
Ye Ding, Liangzong He and Zhao Liu   
, Xiamen University, China; Nanjing University of Science and Technology, China

This paper presents a bi-directional bridge modular switched-capacitor-based resonant DC-DC converter,and the corresponding phase-shift control strategy is proposed for it. Under this control method, bi-directional flow of energy can be realized between the high and low voltage sides. Meanwhile, the output voltage regulation can be achieved 0.15-0.44 times voltage conversion ratio at the step- down mode and above 2.5 times at the step-up mode. In additional, zero-voltage switching (ZVS) operation can be obtained for switches, which improves the system efficiency further. Meanwhile, the working principle of the converter is discussed and the operation parameters are calculated in detail in the converter's optimal working condition. At last, the prototype of proposed converter was built and the experimental results has verified the feasibility and the high efficiency of the proposed converter.

Multi-Phase Rectifiers

Monday, September 19, 1:30PM-4:00PM, Room: 202E, Chair: Luca Zarri, Mahshid Amirabadi

**1:30PM***A Review of Electronic Inductor Technique for Power Factor Correction in Three-Phase Adjustable Speed Drives [#1025]*  
Pooya Davari, Yongheng Yang, Firuz Zare and Frede Blaabjerg   
, Aalborg University, Denmark; The University of Queensland, Australia

Electronic Inductor (EI) techniques are promising approaches for improving the grid-side current quality, and they are suitable for motor drive applications. In this paper, different EI topologies are investigated from the efficiency perspective, including the effect of employing Silicon Carbide (SiC) power devices. Moreover, the influence of partial loading on component sizing in Adjustable Speed Drives (ASDs) is studied. Finally the analytical loss modelling of power switches is utilized for efficiency measurement. The theoretical analyses are verified by experimental benchmarking in an ASD system.

**1:55PM***The Power-Loss Analysis and Efficiency Maximization of A Silicon-Carbide MOSFET Based Three-phase 10kW Bi-directional EV Charger Using Variable-DC-Bus Control [#30]*  
Kevin (Hua) Bai, Chenguang Jiang, Hui Teng and Bo Lei   
, Kettering University, United States

It is expected that wide-bandgap devices like silicon carbide MOSFETs and gallium nitride HEMTs could replace Si devices in power electronics converters to reach higher system efficiency, e.g., a 3-phase 380VAC bidirectional battery charger for electric vehicles. This paper uses the conventional half-bridge LLC topology to build a 10kW all-SiC bidirectional charger. As a well-known topology for the unidirectional charger, it has not been comprehensively explored for the usage of the bidirectional energy flow, which falls into the scope of this paper. A double-pulse-test platform is utilized to provide the accurate power losses, which, combined with the state-space model deriving the accurate switching current waveforms eventually accurately, estimates the system efficiency. Based on this model, to further enhance the system efficiency the DC-bus voltage is varied while keeping the LLC DC-DC converter running at the resonant frequency through the whole power range. Experimental results validated our proposed approach that such topology could realize the bidirectional power flow with zero- voltage-switching turn on. With varying the DC-bus voltage, the V2G and G2V modes reach 96% wall-to-battery efficiency.

**2:20PM***Modular Multi-Parallel Rectifiers (MMR) with two DC Link Current Sensors [#16]*  
Firuz Zare   
, Danfoss Drives A/S, Denmark

Conventional three-phase diode or controlled rectifiers generate current harmonics which affect power quality of distribution networks. This paper presents a novel topology with a front end Modular Multi-Parallel Rectifiers (MMR): Active DC link current controllers are utilized for each rectifier connected to a common DC link capacitor which can reduce line current harmonics emissions significantly. In the proposed topology, two current sensors are utilized in DC link legs to reduce switching ripples of the DC link currents. Analysis and simulations have been carried out to verify the proposed topology and operating modes.

**2:45PM***Comparison of Three-phase Active Rectifier Solutions for Avionic Applications: Impact of the Avionic Standard DO-160 F and Failure Modes [#1157]*  
Uros Borovic, Sisi Zhao, Marcelo Silva, Yann E. Bouvier, Miroslav Vasic, Jesus A. Oliver, Pedro Alou, Jose A. Cobos, Fernando Arevalo, Juan Carlos Garcia-Tembleque, Jorge Carmena, Constantino Garcia and Predrag Pejovic   
, Universidad Politecnica de Madrid, Spain; Indra Sistemas, Spain; Fac. of Electr. Eng., Univ. of Belgrade, Serbia and Montenegro

In aircraft applications, there has been an increasing trend related with the More Electric Aircraft (MEA), which results in rapid rise in the electrical power demand on-board. One of its goals lies in minimizing weight and volume of the electrical subsystem while maintaining good power quality and efficiency. The main purpose of this paper is to present and analyze an electrical design of a three-phase Boost rectifier, a three-phase Buck rectifier and a three-phase Vienna rectifier for output power level of 10 kW and compare them in terms of weight, volume, efficiency etc. Moreover, the design is obliged to comply with specific sections of DO-160 standard for avionic equipment with 230 VAC, 360-800 Hz grid conditions. Even though all proposed solutions satisfy the standard requirements, it will be shown that the Vienna rectifier has the lowest volume and not considering failure modes, the better solution overall. However, due to increased number of semiconductors and additional circuitry required for soft start-up, the Buck rectifier would prove to be the more robust solution failure-wise.

**3:10PM***MultiLevel Asymmetric Single-Phase Current Source Rectifiers [#1611]*  
Montie Vitorino, Louelson Costa, Mauricio Correa and Cursino Jacobina   
, Federal University of Campina Grande, Brazil, Brazil

In this work it is presented a review of the Multilevel Current Source Rectifiers (MCSR), aiming to reduce the number of switches and inductors, thus reducing losses, cost and volume of the converter. Despite the removal of switches and inductors, the control and PWM ensures the correct operating of the converter. Simulations are presented to validate the effective operation of the topology for five-, seven- and nine-level MCSR and experimental results are presented for the five-level topology, using a prototype converter built in laboratory.

**3:35PM***Three-Phase Unidirectional Rectifiers with Open-End Source and Cascaded Floating Capacitor H-Bridges [#1020]*  
Joao Paulo Ramos Agra Mello, Cursino Bradao Jacobina and Mauricio Beltrao Rossiter Correa   
, Universidade Federal de Campina Grande, Brazil

This paper presents two topologies of three-phase semi-controlled rectifiers suitable to open-end configured ac power sources. The rectifiers are composed by a combination of two-level three-phase bridges (controlled, semi-controlled ou uncontrolled), and three single-phase floating capacitor H-bridges. These topologies generate two powered dc-links, each one belonging to a three-phase bridge. They present a reduced number of controlled power switches if compared to other open-end configurations of similar complexity found in the literature. Besides the topologies and dedicated to them, it is proposed a Space Vector Pulse Width Modulation (SV-PWM) approach and a method of floating capacitor voltage control. The PWM approach provides a method for redundancy selection, which allows the floating capacitors voltage regulation by means of the redundant state selection (RSS) technique. Simulation results are shown to validate the proposed topologies, the SV-PWM resolution technique and the control strategy.

Single-Phase Inverters

Monday, September 19, 1:30PM-4:00PM, Room: 203AB, Chair: Aaron Cramer, Roberto Petrella

**1:30PM***A Generic Topology Derivation Method for Single-phase Converters with Active Capacitive DC-links [#1542]*  
Haoran Wang, Huai Wang, Guorong Zhu and Frede Blaabjerg   
, Aalborg University, Denmark; Wuhan University of Technology, China

Many efforts have been made to improve the singlephase power converters with active capacitive DC-link. The purpose is to reduce the overall DC-link energy storage and to achieve a reliable and cost-effective capacitive DC-link solution. A few review papers have already discussed the existing capacitive DC-link solutions, but important aspects of the topology assessment, such as the total energy storage, overall capacitive energy buffer ratio, cost, and reliability are still not available. This paper proposes a generic topology derivation method of single-phase power converters with capacitive DC-links, which derives all existing topologies to our best knowledge, and identify a few new topologies. A reliability-oriented design process is applied to compare the cost of different solutions with the lifetime target of 10 years and 35 years, respectively. It reveals that the most cost-effective solutions varies with the lifetime target.

**1:55PM***Power Decoupling Method for Single Phase PV System using Cuk derived micro-inverter [#529]*  
Anindita Jamatia, Vasav Gautam and Parthasarathi Sensarma   
, Indian Institute of Technology, Kanpur, India

Power decoupling is required to balance the difference between constant power at PV side and double frequency pulsating power at load side in single phase AC system. The balance power is generally handled by circuit passives. This paper proposes decoupled power control for grid connected PV systems using an embedded decoupling capacitor in a doubly grounded boost buck (Cuk) derived micro inverter. The method ensures smaller size of PV terminal capacitor, absence of transformer and also removes the potential hazard to humans in contact with the PV array. Simulation and experimental both result verify the circuit operation and analysis.

**2:20PM***A Multi-port, Isolated PV Microinverter with Low Decoupling Capacitance and Integrated Battery Charger [#1073]*  
Shiladri Chakraborty and Souvik Chattopadhyay   
, Indian Institute of Technology Kharagpur, India

This paper proposes a dual-active bridge (DAB)-based isolated microinverter topology with integrated energy storage capability. A control strategy involving dynamic variation of the phase-shift allows twice line frequency energy buffering to be handled on the high-voltage secondary side, resulting in considerable reduction in decoupling capacitance requirement. Being a DAB- derived structure, most of the devices have the possibility of undergoing zero-voltage-switching (ZVS) turn-on. The topology has further advantages of the battery and PV port currents having very less high-frequency ripple on account of them being inductively interfaced. Working principle of the circuit is first described followed by an explanation of the control scheme. Circuit operation is verified through simulations and open-loop experimental tests on a 250 W hardware prototype.

**2:45PM***A Single Phase Transformerless String Inverter with Large Voltage Swing of Half Bridge Capacitors for Active Power Decoupling [#1485]*  
Jinia Roy, Yinglai Xia and Raja Ayyanar   
, Arizona State University, United States

The transformerless single phase inverters are becoming common due to its advantages of reduced volume, lower cost, and higher efficiency but it has two implementation challenges- high frequency capacitive ground current and decoupling of double line frequency power. This paper proposes an optimized power decoupling topology for a single phase string inverter which addresses both the challenges as well as minimizes capacitance required to decouple the ripple power. Unlike conventional power decoupling techniques in full bridge converters, the proposed technique does not significantly increase the voltage stress on the devices. The combination of a half-bridge inverter and a buck boost converter ensure the complete elimination of high frequency capacitive coupled ground currents. The proposed technique requires only 40 uF/kW at 600 V for power decoupling. A closed loop controller design for the converter is detailed and the experimental results at 1 kW, 120 V, 60 Hz output for closed loop operation are provided.

**3:10PM***A-Source Impedance Network [#469]*  
Yam Siwakoti, Frede Blaabjerg, Veda Prakash Galigekere and Marian K. Kazimierczuk   
, Aalborg University, Denmark; Wright State University, United States

A novel A-source impedance network is proposed in this paper using an autotransformer for realizing converters that demand a very high dc voltage gain. The network utilizes a minimal turns ratio compared to other Magnetically Coupled Impedance Source (MCIS) networks to attain high voltage gain. In addition, the proposed converter draws a continuous current from the source, and hence it is suitable for many types of renewable energy sources. This voltage boost capability has been demonstrated by mathematical derivations, and it is also realized in experiments with an example single-switch 50 kHz, 200 W dc-dc converter.

**3:35PM***A Semi-Two-Stage DC-AC Power Conversion System with Improved Efficiency Based on A Dual-input Inverter [#218]*  
Tiantian Mu, Hongfei Wu, Lei Zhu and Wenying Jiang   
, Nanjing Univ. of Aeronautics and Astronautics, China

A semi two-stage DC-AC power conversion system composed of a Boost DC/DC converter and a novel dual-input inverter is presented in this paper. The low voltage DC source and the output of the Boost DC/DC converter are used as the low-voltage and high-voltage DC input ports, respectively, of the dual-input inverter. So part of the input power can be supplied to the inverter directly and will not be processed by the front-end Boost converter. As a result, the conversion stage, power/current stresses of the Boost converter, and associated power losses are reduced, and the overall conversion efficiency is improved. In addition, the two input ports provide a multi-level voltage to the inverter, which will lower the voltage stresses and switching losses of the switching devices. A 1000W prototype is built and tested to verify effectiveness and advantages of the presented semi two-stage power conversion system.

DC-DC Converters I

Monday, September 19, 1:30PM-4:00PM, Room: 102C, Chair: Praveen Jain, Liangzong He

**1:30PM***Single-Input Multiple-Output Synchronous dc-dc Buck Converter [#1258]*  
Bharath Kumar Sabbarapu, Omar Nezamuddin, Andrew McGinnis and Euzeli dos Santos   
, Indiana University-Purdue University-Indianapoli, United States

This paper proposes a new single-input three-output DC-DC buck converter. The proposed topology has two less switching devices than that of a conventional converter. This reduction in switching devices results in lower cost and a more even distribution of power losses among the switching devices. A comprehensive small signal Modeling and control strategies for the proposed converter will be presented. Simulation and experimental results are presented to validate the theoretical expectations. The simulation is performed using PSIM, and the laboratory experiment is performed with a proof of concept prototype.

**1:55PM***Dual-Input Dual-Output Single-Switch Dc-Dc Converter for Renewable Energy Applications [#533]*  
Aluisio Alves de Melo Bento, Edison Roberto Cabral da Silva and Diego Alberto Acevedo Bueno   
, Federal University of Campina Grande, Brazil

Normally, a photovoltaic energy generation system is composed of dc-dc converter, dc-ac converter, and their corresponding control circuits. This paper presents a two-input two-output single switch dc-dc converter with a reduced number of switches, drivers and controllers. The proposed converter performs independent energy flux control for each dc input while producing two symmetrical, automatically balanced, output voltages. A very simple MPPT technique, based on fractional voltage control technique, is employed to confirm the performance of proposal. Simulation and experimental results verify the proposed scheme feasibility.

**2:20PM***A High Step-Up Interleaved Converter with Coupled Inductor and Voltage-Lift Technique [#261]*  
Atsushi Matsuda and Hirotaka Koizumi   
, Tokyo University of Science, Japan

This paper proposes a high step-up interleaved converter with coupled inductor and voltage-lift technique. The proposed converter achieves high voltage gain by employing coupled inductor and voltage-lift technique. Moreover, low input current ripple is realized by using interleaved technique. The energy in the leakage inductance of the coupled inductor is recycled to the output load. The voltage stresses on the main switches are reduced and the voltage spikes across the main switches are alleviated. This paper shows a theoretical analysis in steady-state and experimental results with a small-scale prototype circuit.

**2:45PM***Single Resonant Cell Based Multilevel Soft-Switching DC-DC Converter for Medium Voltage Conversion [#273]*  
Jiepin Zhang, Trillion Q Zheng, Xiaofeng Yang and Miao Wang   
, Beijing Jiaotong University, China

A multilevel soft-switching DC-DC converter with only one resonant cell for medium voltage conversion is proposed in this paper. Two control strategies for the converter are analyzed and compared. For the proposed converter, all dc capacitors can achieve voltage self-balanced under open loop control. All switches and diodes operate in soft-switching condition without sacrificing reliability. Finally, a prototype of a four-level DC-DC converter is given and the validity of the converter is verified by experimental results.

**3:10PM***Unified Model of High Voltage Gain DC-DC Converter with Multi-cell Diode-Capacitor/Inductor Network [#1364]*  
Yan Zhang, Liu Jinjun, Dong Zhuo and Yanfei Liu   
, Xi'an Jiaotong University, China; Queen's University, Canada

Multi-cell diode-capacitor/inductor based boost derived DC-DC converter provides a simple solution for high step-up voltage regulation in solar and fuel cell generation. However, many passive components increase the order of system model and complexity. Transient modeling analysis reveals that time constant of each component in diode-capacitor/inductor network is much smaller than that of other circuit if the directly charging and discharge processes between capacitor through diode is fast enough. The voltage/current relationship of each capacitor/inductor in multi-cell network is fixed. Multi-cell diode-capacitor/inductor network can be seemed as multi-stage DC transformer. Based on the unique feature, this paper proposes the reduced-order modeling approach for high step-up DC-DC converter with multi-cell diode-capacitor/inductor network. Finally, simulation and experiments verify the correctness and effectiveness of new modeling approach. The unified reduced-order model contributes to better understanding of circuit characteristic and simplification of controller parameters design.

**3:35PM***Comparative Evaluation of a Triangular Current Mode (TCM) and Clamp-Switch TCM DC-DC Boost Converter [#1011]*  
Oliver Knecht, Dominik Bortis and Johann Walter Kolar   
, ETH Zurich, Switzerland

For the power management of a wireless power transfer system for implantable mechanical heart pumps, an additional boost DC-DC converter stage is needed in order to control the power delivered to the implant. Particularly, battery powered and implantable medical devices pose special demands on the efficiency and/or power density of the employed converters. Accordingly, soft-switching and/or high switching frequencies must be targeted. Modulation schemes that allow for Zero-Voltage-Switching (ZVS) such as Triangular Current Mode (TCM) offer a highly efficient operation, but suffer from a large operating frequency variation, which is mainly limited by the digital control. Therefore the Clamp-Switch TCM (CL-TCM) converter can be employed which allows also for the control of the switching frequency variation. In this paper, the CL-TCM and the TCM converter are compared regarding the power conversion efficiency and the power density of the converter. Since the CL-TCM converter is not well known in the literature, the converter is analysed in detail and a modulation scheme is explained that allows for ZVS for all switches in the entire range of operation. In addition, the requirements for ZVS and a control scheme (i.e. timing calculations) are provided for the converter in order to limit the maximum switching frequency. The modulation and control scheme are verified with a hardware prototype. Finally, the performance of the CL-TCM converter is measured and compared to the performance of the converter operated in TCM mode. The measurements show that the CL-TCM converter offers similar performance compared to the TCM operation at lower inductor power density, but has the advantage of a significantly reduced switching frequency variation. In applications, where a very high power density is needed, the TCM converter outperforms the CL-TCM converter in terms of efficiency.

DC-DC: Dual Active Bridge

Monday, September 19, 1:30PM-4:00PM, Room: 102E, Chair: Regan Zane, Zhiqiang Guo

**1:30PM***Analytically Constrained ZVS Operation To Reduce Commutation Losses for High Boost Dual-Active Bridge Converters [#814]*  
Jan Riedel, Donald Grahame Holmes, Brendan Peter McGrath and Carlos Teixeira   
, Robert Bosch (SEA) Pte Ltd, Singapore; RMIT University, Australia

Dual Active Bridge (DAB) converters offer an unmatched capability to transfer energy in either direction between two DC sources, especially when they are operated under Zero Voltage Switching (ZVS) conditions. However, the parasitic commutation inductance within the bridge phase leg devices can still lead to significant energy losses at device turnoff despite operating under ZVS conditions. These losses can become significant when one bridge has a low DC bus voltage and a consequential high magnitude output current. This paper shows how harmonic decomposition analysis can be used to constrain the bridge circulating currents to their minimum possible values at the point of phase leg commutation while still ensuring that ZVS operation is maintained. This can be used to improve the overall DAB performance under low voltage, high current operating conditions of one DC port. The capability of the theoretical analysis process is confirmed by matching experimental results for a reference DAB system.

**1:55PM***Passive Auxilliary Circuit for ZVS Operation of A Wide-DC-Range Dual-Active-Bridge Bidirectional Converter for Transportation Applications [#1477]*  
Alireza Safaee, Praveen Jain and Alireza Bakhshai   
, Osram Sylvania, United States; Queen's University, Canada

In this paper, an isolated bidirectional converter is proposed for transportation applications such as midsize electrified airplanes. Using time- domain analysis a modulation scheme is suggested that allows the converter to transfer any power level up to the nominal value over the entire wide dc range of terminal voltages. A single robust and low cost passive auxiliary is introduced to guarantee zero voltage switching of all the eight switches for any combination of dc voltage and power levels. Effectiveness of the modulation scheme in achieving zero current switching was experimentally confirmed.

**2:20PM***Charge-Based ZVS Modulation of a 3-5 Level Bidirectional Dual Active Bridge DC-DC Converter [#661]*  
Georgios Sfakianakis, Jordi Everts, Henk Huisman, Thomas Borrias, Cornelis Wijnands and Elena Lomonova   
, Eindhoven University of Technology, Netherlands

This paper presents a charge-based Zero Voltage Switching (ZVS) modulation strategy for the 3 Level - 5 Level (3-5L) Dual Active Bridge (DAB) DC-DC converter. The DAB combines a primary-side full bridge and a secondary side mixed bridge (i.e. a 3-level T-type leg with a half-bridge leg), linked by a high-frequency transformer and an inductor. A ZVS modulation strategy is presented, in which a charge-based model of the non-linear parasitic output capacitances of the switches is used to accurately describe the ZVS constraints. Moreover, commutation inductances are included to extend the ZVS region to the entire operating range. The configuration of the secondary-side bridge facilitates increased flexibility compared to a full bridge configuration, in order to reduce the RMS current in the switches, inductor, and transformer. The nominal power of the investigated converter is 2.8 kW with input voltage range from 8 V to 16 V and output voltage range from 175 V to 450 V. The RMS currents of the 3-5L DAB are compared with those of a typical 3-3L DAB, applying the proposed modulation strategy in the 3-5L DAB, and a similar strategy previously proposed in literature in the 3-3L DAB.

**2:45PM***Parallel-Connected Bidirectional Current-Fed Dual Active Bridge DC-DC Converters with Decentralized Control [#76]*  
Deshang Sha, Wenqi Yuan, Guo Xu, Fulin You and Jianliang Chen   
, Beijing Institute of Technology, Automation, China

A decentralized control strategy with improved droop control is proposed for parallel-connected current-fed bidirectional DC-DC converters to achieve the flexible power architecture and modular design. The step-up or step-down function depends on the power flow direction. An improved droop control strategy is implemented by sensing the high-voltage side (HVS) voltage and low-voltage side (LVS) current. The operation principle and power sharing characteristics are analyzed. The system stability is demonstrated in detail based on small-signal model. Excellent power sharing can be achieved not only under steady state but also in dynamics. Besides, the system has the hot-swapping feature. A 2.5kW prototype composed of two modules is established to verify the effectiveness of the proposed control strategy.

**3:10PM***Asymmetrical Duty-Cycle Control of Three-Phase Dual-Active Bridge Converter for Soft-Switching Range Extension [#1063]*  
Jingxin Hu, Nils Soltau and Rik W. De Doncker   
, RWTH Aachen University, Germany

The three-phase dual-active bridge (DAB3) converter is a promising topology for high-power conversion in future dc grids due to bidirectional power flow, inherent soft-switching capability and reduced filter size. However, the conventional single phase-shift control (SPS) does not allow the soft- switching operation with large voltage variations in light load conditions. This paper proposes an asymmetrical duty-cycle control (ADCC) method for the DAB3 to extend the soft-switching range by realizing zero-current switching (ZCS). Three triangular and trapezoidal current modes are introduced, analyzed and seamlessly combined. It is established through loss analysis that the proposed modulation schemes reduce both the semiconductor and transformer losses substantially in light load conditions. By employing ADCC, the DAB3 can achieve high efficiency even under low load conditions. The proposed method has been validated by experimental results.

**3:35PM***Proposal of Dual Active Bridge Converter with Auxiliary Circuit for Multiple Pulse Width Modulation [#253]*  
Kazuaki Kojima, Yukinori Tsuruta and Atsuo Kawamura   
, Yokohama National University, Japan

A novel multiple pulse generation of DAB (dual active bridge) converter is proposed based on the auxiliary circuit for realization of complete soft-switching. The proposed auxiliary circuit enables multiple pulse width modulation (MPWM) with soft- switching. MPWM can transfer more power to the secondary side with the less peak inductor current when the output voltage ratio is very different from the transformer turn ratio, compared with the one pulse operation. It is verified through the experiments that DAB with the proposed auxiliary circuit was operated in the two-pulse soft-switching mode.

Electromagnetic Interference (EMI) in Power Converters

Monday, September 19, 1:30PM-4:00PM, Room: 102A, Chair: Shuo Wang, Sung Yeul Park

**1:30PM***A Simple Low-Cost Common Mode Active EMI Filter Using a push-pull Amplifier [#884]*  
Dongil Shin, Changwoo Son, Seonho Jeon, Bongjin Cho, Jinwook Han and Jingook Kim   
, Ulsan National Institute of Science and Tech, Korea (South); Home Appliance Control Research Division LGE, Korea (South)

A simple low-cost active EMI filter (AEF) without transformers is proposed. The equivalent circuit model of the proposed AEF is built, and a block diagram is extracted for efficient feedback analysis. The feedback loop gain and the performance of the AEF are calculated and validated by comparison with SPICE simulations. The proposed AEF enlarges the effective value of Y-capacitors. The AEF is manufactured for the application of a 2.2kW resonant inverter, and the performance is demonstrated by measurements of the conducted emissions.

**1:55PM***Two-capacitor Transformer Winding Capacitance Models for Common-Mode EMI Noise Analysis in Isolated DC-DC Converters [#1715]*  
Huan Zhang and Shuo Wang   
, University of Florida, United States

For isolated DC-DC power converters, the inter-winding parasitic capacitance of the transformer is usually one of the main paths for common-mode (CM) noise. In order to simplify the CM noise analysis, this paper proposes a two-capacitor transformer winding capacitance model. The model is derived based on general conditions so it can be applied to different isolated converter topologies. A measurement technique is also proposed to obtain the lumped capacitance for the model. The CM noise models of several isolated converter topologies are analyzed with the proposed two-capacitor transformer winding capacitance model to achieve simplicity. Finally, the proposed transformer winding capacitance model and measurement technique are verified by simulations and experiments.

**2:20PM***Performance of Common-Mode-Voltage-Cancellation PWM Strategies with Consideration of Commutation Residues due to Double-Switching Waveforms [#985]*  
Mehdi Messaoudi, Arnaud Videt, Nadir Idir, Hocine Boulharts and Heu Vang   
, Schneider Toshiba Inverter, France; Univ. Lille, L2EP, France; Toshiba Schneider Inverter, Japan

This paper focuses on pulse-width modulation (PWM) strategies that aim at cancelling common-mode (CM) voltage generated by power converters. In the typical use case of frequency converters, such strategies perform simultaneous switching between different inverter legs, so that their effects on CM voltage cancel each other. Doing so, the resulting CM voltage is reduced to mere commutation residues because simultaneous switching voltage waveforms may not be identical nor perfectly synchronous. Based on a PWM strategy that theoretically cancels the CM voltage generated by a variable-speed drive, this paper highlights the influence of desynchronization effects, commutation speeds, and different waveforms due to instantaneous currents, on the resulting CM voltage spectrum. Practical rules are derived in order to optimize the electromagnetic compatibility (EMC) performance of such PWM strategies.

**2:45PM***Identification of the Temporal Source of Frequency Domain Characteristics of SiC MOSFET Based Power Converter Waveforms [#762]*  
Samuel Walder, Xibo Yuan, Ian Laird and J. O. Dalton Jeremy   
, University of Bristol, United Kingdom

Certain Electromagnetic Interference (EMI) performance characteristics that occur in data taken from practical systems are often difficult to attribute to time domain features as waveforms will tend to deviate from the idealized analytical case. This paper shows that by taking multiple derivatives of experimental data and comparing this with the expected characteristics of a typical switching waveform it is possible to understand exactly which features of a given temporal waveform lead to certain spectral characteristics. It is also shown through analysis of analytical methods and experimental data that the smoother the transitions of a waveform the faster the roll off of the spectral content and hence the better the EMI performance.

**3:10PM***Resonance Phenomenon Influencing the Conducted-Mode Emission Test [#1048]*  
Christian Wolf   
, Grundfos A/S, Denmark

When measuring conducted-mode emission noise on power electronics equipment in order to check for compliance with the CISPR 14-1 emission standard, the measurement results often contain surprisingly high levels of conducted emission at frequencies between 10 MHz and 30 MHz. The high level of conducted emission is present even if the attenuation of the EMI filter in this frequency range should be more than adequate when checked. In the present paper it will be shown that the reason for exceeding the limits can be a resonant phenomenon involving the mains cable, the device under test and the shielded test chamber. This resonant problem cannot be solved by increasing the EMI filter attenuation. The paper explains how the resonance is excited, why increasing the filter attenuation cannot solve the problem and how the problem can be avoided.

**3:35PM***Modeling, Analysis and Design of Differential Mode Active EMI Filters with Feedforward and Feedback Configurations for AC-DC Converters [#1533]*  
Rajib Goswami, Shuo Wang and Zhang Yingjie   
, University of Texas at San Antonio, United States; University of Florida, United States

This paper developed models for DM electromagnetic interference (EMI) input filters in AC-DC converters. The models are developed based on the circuit structures and control configurations. The models are developed for feedback, feedforward, feedforward-feedback and feedback-feedforward configurations. The closed loop gains are derived respectively. Based on the closed loop gain models, the open loop characteristics required for high performance active filters are determined. A passive filter topology which enhances the performance of the active filter is identified. The stability of active filters is analyzed and compared based on the developed models. The analysis is validated with both simulations and experiments. It is shown that the developed models can predict stability and help compensation design for active filters.

Modeling and Control of DC-AC converters I

Monday, September 19, 1:30PM-4:00PM, Room: 202D, Chair: Wim van der Merwe, Yi Deng

**1:30PM***Compensation for Inverter Nonlinearity Considering Voltage Drops and Switching Delays of Each Leg's Switches [#1499]*  
Myeong-Chan Kang, Sang-Hoon Lee and Young-Doo Yoon   
, Myongji University, Korea (South)

This paper proposes a compensation method for inverter nonlinearity for an accurate voltage synthesis. The inverter nonlinearity is caused by dead-times, voltage drops and switching delays and parasitic output capacitance of semiconductor switches, and propagation delays in the gate drive circuits. This paper regards dead-times, voltage drops and switching delays of semiconductor switches as dominant voltage distortion factors. Analyzing those factors of each leg, the proposed method compensates nonlinearity of each leg of inverters. As a result, accurate voltages can be synthesized. Experimental results verify the effectiveness of the proposed method.

**1:55PM***Small-signal Terminal-Characteristics Modeling of Three-Phase Droop-Controlled Inverters [#1628]*  
Zeng Liu, Jinjun Liu, Dushan Boroyevich, Rolando Burgos and Teng Liu   
, Xi'an Jiaotong University; Virginia Tech, China; Xi'an Jiaotong University, China; Virginia Tech, United States

Droop-controlled inverters are widely employed as power sources in three-phase AC power electronics system, such as distributed generation, while the interaction between the source and the load may lead overall system to be unstable. Terminal-characteristics based stability criteria are very attractive for analyzing the stability of three-phase AC power electronics system. However, the systems, composed by droop-controlled inverters, exhibit the dynamical variation of fundamental angular frequency, and existing stability analysis approaches are just suitable for systems with constant fundamental angular frequency. To overcome this problem, this paper proposes small-signal terminal-characteristics model of the three-phase droop-controlled inverter covering the dynamic of fundamental angular frequency, and both current mode operation and voltage mode operation are taken into account. Finally, the proposed model is verified in frequency domain.

**2:20PM***Enhancement of Current and Voltage Controllers Performance by Means of Lead Compensation and Anti-Windup for Islanded Microgrids [#766]*  
Federico de Bosio, Luiz Antonio de Souza Ribeiro, Francisco Freijedo, Josep Guerrero and Michele Pastorelli   
, Politecnico di Torino, Italy; Federal University of Maranhao, Brazil; Ecole Polytechnique Federale de Lausanne, Switzerland; Aalborg University, Denmark

The decoupling of the capacitor voltage and inductor current has been shown to improve significantly the dynamics performance of voltage source inverters in isolated microgrids. However, still the computation and PWM delays limit the achievable bandwidth. A technique based on a lead compensator structure is proposed to overcome this limitation. It is shown how a widen bandwidth for the current loop with still well damped characteristics allows to enlarge the outer voltage loop bandwidth. These features are demanding requirements in high performance islanded applications. Discrete-time domain implementation issues of an anti-wind up scheme are discussed as well. In fact, algebraic loops can arise if the wrong discretization method is used making unfeasible the real-time implementation of digital controllers. Experimental tests in accordance with the standards for UPS systems verify the theoretical analysis.

**2:45PM***DC-Link Current Ripple Component RMS Value Estimation Considering Anti-Parallel Diode Reverse Recovery in Voltage Source Inverters [#144]*  
Jing Guo and Ali Emadi   
, McMaster University, Canada

To estimate the RMS value of the DC-link ripple current more accurately, a method is developed considering the reverse recovery of the anti-parallel diode in voltage source inverters (VSIs). In this paper, using the analysis of the inverter DC-link current and anti-parallel diode reverse recovery, calculations are implemented based on the SPWM technique. According to the calculations and simulation and experimental results, it is shown that the calculated ripple current RMS values are higher and closer to the actual values when the diode reverse recovery is considered. In addition, inverter switching frequency also influences this value. Comparing with the experimental results, the error of the DC-link ripple current RMS value estimated by the proposed method vary under different inverter operating conditions and are between 0.1% and 10.5%.

**3:10PM***Digital Dead-Beat and Repetitive Combined Control for Stand-Alone Four-Leg VSI [#727]*  
Alessandro Lidozzi, Luca Solero, Fabio Crescimbini, Chao Ji and Pericle Zanchetta   
, ROMA TRE University, Italy; The University of Nottingham, United Kingdom

This paper deals with a newly conceived combine control topology. Dead-Beat and Repetitive controllers are proposed to operate jointly in 4-leg VSI for stand-alone applications. In such mode of operation, dedicated controller has to regulate the inverter output voltages, which are measured at the output of the power filter. Each control topology exhibits some specific features. Dead-Beat can rapidly compensate output voltage variations due to load changes; on the contrary, Repetitive Control can provide the required harmonic compensation capabilities that are mandatory to comply with the Standards, when balanced and unbalanced non-linear loads have to be fed.

**3:35PM***Modeling, Analysis, and Impedance Design of Battery Energy Stored Single-Phase Quasi-Z-Source Photovotaic Inverter System [#1080]*  
Yushan Liu, Haitham Abu-Rub, Baoming Ge, Robert S. Balog and Yaosuo Xue   
, Texas A and M University at Qatar, Qatar; Texas A and M University, United States; Oak Ridge National Laboratory, United States

The battery energy stored quasi-Z-source (BES-qZS) based photovoltaic (PV) power generation system combines advantages of the qZS inverter and the battery energy storage system. However, the second harmonic (2W) power ripple will degrade the system's performance and affect the system's design. An accurate model to analyze the 2W ripple is very important. The existing models did not consider the battery, and with the assumption L1=L2 and C1=C2, which causes the non-optimized design for the impedance parameters of qZS network. This paper proposes a comprehensive model for single-phase BES-qZS-PV inverter system, where the battery is considered and without any restriction of L1, L2, C1, and C2. A BES- qZS impedance design method based on the built model is proposed to mitigate the 2W ripple. Simulation and experimental results verify the proposed 2W ripple model and design method.

Induction Machines

Monday, September 19, 1:30PM-4:00PM, Room: 101A, Chair: Andy Knight, Andrea Cavagnino

**1:30PM***High Torque Density Induction Motor with Integrated Magnetic Gear [#849]*  
Dalia Abdelhamid and Andrew Knight   
, University of Calgary, Canada

This paper presents a design process to integrate a magnetic gear with an induction machines. The resulting integrated machine has the potential to offer a high torque density with asynchronous speed characteristics. Such characteristics may be desirable for applications that require sensorless operation or may be subject to severe backlash or jamming. The paper presents some of the difficulties in the design process as compared to the design process for PM machines. A prototype design at small scale is developed, and simulation results demonstrate the potential for high torque density low-speed high-torque induction motor.

**1:55PM***Accurate Determination of Induction Machine Torque and Current versus Speed Characteristics [#776]*  
Emmanuel Agamloh, Andrea Cavagnino and Silvio Vaschetto   
, Advanced Energy, United States; Politecnico di Torino, Italy

The determination of induction machine torque and current speed characteristics relies on methods based on either direct testing or calculation, using machine equivalent circuit. Both methods may lead to significant errors. The paper discusses the challenges encountered using these methods and an approach is presented in the paper to overcome the inherent challenges. The proposed approach considers saturation and compensates for skin effect and machine temperature to improve accuracy. Five induction motors of different pole pairs were analyzed and tested to provide understanding of the underlying issues of predicting torque and current characteristics of induction machines. The findings indicate that, for direct testing, multiple data points closer to nominal voltage are required. In the case of equivalent circuit modeling, proper correction of the model for temperature and saturation leads to improved prediction of the torque characteristics of general purpose induction machines.

**2:20PM***The Novel SLIM Method for the Determination of the Iron Core Saturation Level in Induction Motors [#1556]*  
Konstantinos N. Gyftakis   
, Coventry University, United Kingdom

Lately, a new diagnostic mean has been introduced for reliable fault diagnosis in delta-connected induction motors. This diagnostic mean is the zero-sequence current frequency spectrum. It will be shown in this paper that, the zero- sequence current waveform can be reliably used for identifying the induction motor's iron core saturation level. So in this work, simulations with the Finite Element Method and experimental testing are carried out, with the healthy induction motor operating under different load levels. The paper proposes a novel method called SLIM for reliable induction motor saturation level determination.

**2:45PM***Rotor Design to Reduce Secondary Winding Harmonic Loss for Induction Motor in Hybrid Electric Vehicle Application [#438]*  
Haodong Li and Keith Klontz   
, Advanced MotorTech, United States

Induction motor rotor designs are investigated in this paper to reduce secondary winding harmonic losses in hybrid electric vehicle (HEV) application. The induction motor is more and more popular to use for the traction drive, but its' secondary winding harmonic losses are significantly higher than the usual when having high frequency and high power density in the HEV application. Thus, the major cause of the high secondary winding losses is analyzed and evaluated in the paper. The losses of rotor bars due to harmonic field are calculated and analyzed for a typical eight pole induction motor by using the finite element method (FEM). Several rotor structures are proposed to decrease the harmonic losses and improve efficiency. Finally, the rotor design methods of the induction motor are compared to achieve a high efficiency and high power density based on the reduced harmonic losses, increased efficiency and output torque. The results show the secondary winding losses of the induction motor can be reduced by up to 43% when using the new rotor structure design.

**3:10PM***A Novel In Situ Efficiency Estimation Algorithm for Three-Phase Induction Motors Operating with Distorted Unbalanced Voltages [#9]*  
Maher Al-Badri, Pragasen Pillay and Pierre Angers   
, Concordia University, Canada; Hydro-Quebec, Canada

This paper presents a novel algorithm for in situ efficiency estimation for induction motors operating with distorted unbalanced voltages. The proposed technique utilizes the genetic algorithm, IEEE Form F2-Method F1 calculations, large motor test database and a new stray-load loss formula. The technique is evaluated by testing 3 small- and medium-sized induction motors with 11 different combinations of voltage unbalance and total harmonic distortion. The results showed acceptable accuracy. The technique may be used as a potential industrial tool that can help derate induction motors in the presence of voltage unbalance and harmonics distortion.

**3:35PM***Development and Efficiency estimation of a Regenerative Test Rig for Induction Motor Testing [#670]*  
Jamlick Murimi Kinyua, Mohamed A. Khan and Paul Barendse   
, University of Cape Town, South Africa

This paper presents the development and error analysis of a flexible test rig which is intended for emulating the static and dynamic characteristics of some mechanical loads found in industry. The test rig will provide a laboratory- based platform for assessing the efficiency of inverter-fed induction motors (IM) within a wide range as well that of variable speed drives (VSDs). The use of an Active Front End (AFE) with regenerative capabilities allows the power generated by the motor drive to be recycled within the system. An in-depth error analysis is conducted on the complete system. This is done by analyzing raw data obtained by means of 2 commercial instruments. Detailed comparisons of the error bands were done for the results obtained.

Prof. Subhasis Nandi Memorial Session: Diagnostics of Electric Machines

Monday, September 19, 1:30PM-4:00PM, Room: 102B, Chair: Hamid Toliyat, Sang Bin Lee

**1:30PM***A Voltage Based Approach for Fault Detection and Separation in Permanent Magnet Synchronous Machines [#248]*  
Reemon Haddad, Cristian A. Lopez, Shanelle Foster and Elias Strangas   
, Michigan State University, United States

Different faults in Permanent Magnet Synchronous Machines will cause various and independent changes to the machine magnetic flux distribution, which will cause different changes to the machine parameters and performance. These changes will be reflected in the machine flux linkages, which can be determined from the machine voltages. In this paper, a method is proposed to detect and separate three types of faults in Permanent Magnet Synchronous Machines: static eccentricity, demagnetization, and turn-to-turn short circuit. The proposed method is based on using the direction of the shift in the commanded d and q axis voltages while the machine is operating at steady state. Simulation tests using Finite Element Analysis software (MAGSOFT- Flux2D) were performed under healthy and faulted conditions on a 3 phase 10- pole fractional slot concentrated winding Permanent Magnet Synchronous Machine. Experimental tests were carried out and compared with Finite Element Analysis for the same machine under demagnetization and turn-to-turn short circuit faults. The effects of the speed and temperature variations were simulated to validate the detection method under different operating conditions.

**1:55PM***Permanent Magnet Generator Turn Fault detection Using Kalman Filter Technique [#1081]*  
Bo Wang, Jiabin Wang, Antonio Griffo, Vipulkumar I. Patel, Zhigang Sun, Ellis Chong and Riona Smitham   
, The University of Sheffield, United Kingdom; Rolls-Royce plc, United Kingdom

In this paper, a stator turn fault detection strategy is developed for a permanent magnet (PM) generator system. Unlike conventional power generation systems, the output of the PM generator is directly rectified by an uncontrolled diode bridge. The only accessible signal is the DC link current/voltage. As a result, most existing detection techniques based on the phase current/voltage signals are not applicable. Instead, the 2nd and 6th harmonics of the DC link current are exploited for turn fault detection and they are extracted by a Kalman filter. It is shown that the phase unbalance caused by a turn fault gives rise to significant increase in the 2nd harmonic DC link current. Consequently, the dominant harmonic under healthy and fault conditions are of the 6th and 2nd orders, respectively. Hence, the turn fault can be detected by comparing the magnitudes of the two harmonics. The detection method is assessed by extensive simulation under various fault scenarios. It is shown that the developed Kalman filter method exhibits significant advantages in response time and computation effort than online fast Fourier transform (FFT) based techniques.

**2:20PM***Influence of Blade Pass Frequency Vibrations on MCSA-based Rotor Fault Detection of Induction Motors [#128]*  
Yonghyun Park, Sang Bin Lee, Myung Jeong, Jose Antonino-Daviu and Mike Teska   
, Korea University, Korea, Republic of; UNIVERSITAT POLITECNICA DE VALENCIA, Spain; SKF Condition Monitoring Center, United States

Motor current signature analysis (MCSA) has recently become widespread in industry for on-line detection of rotor cage faults in induction motors for preventing forced outages. Although it can provide low cost, remote monitoring of rotor faults, cases of false indications have been reported, where the causes of some false indications are still unknown. It is shown for the first time in this work that high-amplitude blade pass frequency (BPF) vibrations produced in pumps, fans, or compressors can cause false rotor fault indications, if the number of motor poles is an integer multiple of the number of blades. The influence of BPF vibration on MCSA based rotor fault detection is analyzed, and it is shown that the interaction between BPF vibration and rotor faults can produce false positive and negative fault indications. Alternative test methods capable of separating the influence of the BPF vibration and rotor faults are suggested for avoiding false MCSA alarms. The claims made in the paper are verified experimentally on a custom-built 380 V induction motor-centrifugal pump system setup.

**2:45PM***Stator Insulation Quality Assurance Testing for Appliance Motors with Aluminum Windings [#127]*  
Daewoong Choi, Taejune Kang, Sang Bin Lee, Jaegyu Kim and Jihoon Kim   
, Samsung Electronics, Korea, Republic of; Korea University, Korea, Republic of

A number of appliance manufacturers have recently replaced the motor stator winding material from copper (Cu) to aluminum (Al) to reduce the product cost in the competitive global appliance market. Although reduction in the motor cost could be achieved, a noticeable increase in the failure rate due to stator insulation breakdown was observed. In this paper, increased failures in Al winding stator insulation is investigated for 230 V, 50 W single phase induction fan motors used in the outdoor unit of air conditioners (A/C). Since the motors with defects or failures could not be screened out with the quality assurance tests (QA) that were applied to Cu winding motors, new QA test methods are evaluated for screening out the units with high risk of failure. The investigation shows that partial discharge (PD) measurement under surge excitation can serve as an effective means of screening out the units that are likely to fail. The claims made in the paper are verified through comparative experimental surge PD testing on Al and Cu winding motors before and after accelerated degradation.

**3:10PM***Robust detection of rotor winding asymmetries in wound rotor induction motors via integral current analysis [#50]*  
Jose Antonino-Daviu, Alfredo Quijano-Lopez, Vicente Climente-Alarcon and Carlos Garin Abellan   
, UNIVERSITAT POLITECNICA DE VALENCIA, Spain; AALTO UNIVERSITY, Finland; FYM ITALCEMENTI GROUP, Spain

Current analysis has been widely employed in academy and industry for the diagnosis of rotor damages in cage induction motors. The conventional approach based on the FFT analysis of steady-state current (MCSA) has been recently complemented with the development of alternative techniques that rely on the time-frequency analysis of transient quantities of the machine. However, the application of current-based methodologies to wound rotor induction motors (WRIM) has been much less studied. The present work proposes the application of an integral methodology based on the analysis of both stationary and transient currents for the diagnosis of winding asymmetries in WRIM. The method, based on up to five different fault evidences, is validated in laboratory motors and it is subsequently applied to a large field motor (1,500 kW) that was showing signs of abnormal rotor functioning. The results prove that the method is of interest for the field since it helps to ratify without ambiguity the existence of eventual asymmetries in the rotor windings.

**3:35PM***Asynchronous Motors Fault Detection Using ANN and Fuzzy Logic Methods [#1444]*  
Negin Lashkari, Hamid Fekri Azgomi, Javad Poshtan and Majid Poshtan   
, Iran University of Science and Technology, Iran; California Polytechnic State University, United States

Detection of stator faults in their early stage is of great importance since they propagate rapidly and may cause further damage to the motor. Some variations in induction motors such as torque load anomalies must be considered in order to reliably detect stator faults. This paper presents robust artificial intelligence (AI) techniques for interturn short circuit (ITSC) fault detection of stator in three phase induction motors. In this work, the focus is first on the application of artificial neural networks and then fuzzy logic systems to reduce significantly the effect of load variations on fault detection procedure. The proposed ANN methodology has the merit to detect and locate ITSC fault, while the Fuzzy approach is capable of detecting and diagnosing the severity of ITSC fault. The simulation and experimental results are also given to verify the efficiency of both approaches under ITSC fault and load change.

Control of Electric Drives I

Monday, September 19, 1:30PM-4:00PM, Room: 101CD, Chair: Radu Bojoi, Roberto Petrella

**1:30PM***Minimizing Torque Ripple of Highly Saturated Salient Pole Synchronous Machines by Applying DB-DTFC [#748]*  
Michael Saur, Daniel Gaona, Jelena Zdravkovic, Bastian Lehner, Robert Lorenz and Dieter Gerling   
, Universitaet der Bundeswehr, Germany; University of Oviedo, EMMC STEPS Consortium, Spain; University of Wisconsin-Madison, United States

DB-DTFC is a flux-observer-based high bandwidth digital, closed-loop torque control law that achieves the commanded torque at the end of each switching period. When flux estimation is accurate, instantaneous torque is fed back and unwanted pulsating torque is inherently minimized. This research presents real time flux-observer-based torque ripple estimation of a highly nonlinear synchronous reluctance machine (SynRM). Saturation and cross-saturation are incorporated directly into the control law and considered in each switching period. Deadbeat torque response and torque ripple reduction is demonstrated experimentally. FEM-simulations validate the torque ripple minimization.

**1:55PM***Using Volt-sec. Sensing to Directly Improve Torque Accuracy and Self-Sensing at Very Low Speeds [#1260]*  
Yukai Wang, Naoto Niimura, Ben Rudolph and Robert Lorenz   
, University of Wisconsin - Madison, WEMPEC, United States; TMEIC, Fuchu work, Japan; TMEIC Corporation, Roanoke, United States

As a result of dead-time, device on-state voltage drop, DC bus voltage error and fluctuation, etc., Volt-sec. errors degrade precise control of torque and flux linkage, particularly at low speeds. This is true for deadbeat-direct torque and flux control (DB-DTFC) which directly manipulates the Volt-sec. vector sourced by inverters as well as for indirect field oriented control (IFOC) drives. This paper introduces a real-time sensing scheme to measure the terminal Volt-sec. vector for each switching period with negligible phase delay. Based on Volt-sec. sensing, a model reference adaptive system (MRAS)- based approach is developed to decouple Volt-sec. errors from inverter nonlinearity and DC bus voltage. By delivering accurate Volt-sec. for each switching period, torque and flux control accuracy, self-sensing performance and parameter estimation accuracy are significantly enhanced.

**2:20PM***Torque Ripple Reduction for 6-stator/4-rotor-pole Variable Flux Reluctance Machines by Using Harmonic Field Current Injection [#88]*  
Beomseok Lee and Zi-Qiang Zhu   
, The University of Sheffield, United Kingdom

The variable flux reluctance machines (VFRMs) are electrically field excited synchronous machines having both field and armature windings on the stator. In order to investigate the torque production of the 6/4 VFRM, an instantaneous torque equation is derived for the first time considering the inductance harmonics by using Fourier series. According to the equation, the undesirable torque ripples having multiples of third harmonic exist due to the inductance harmonics of the field and armature windings. Hence, the harmonic field current injection methods are proposed for the torque ripple reduction. The torque waveforms calculated by 2D-finite element analysis (FEA) are compared with the predicted results from the derived torque equation. Although the methods are proposed at which the magnetic saturation does not occur, the torque ripple can be also reduced in saturation region. Since the proposed method utilizes the machine parameters the influence of the parameter mismatch is investigated. It shows that the torque ripple reduction performance is not affected much unless the fundamental component of nominal inductance is underestimated. The experimental results verify that the proposed approach can effectively reduce the torque ripple in the VFRM.

**2:45PM***Novel On-Line Optimal Bandwidth Search and Auto Tuning Techniques for Servo Motor Drives [#250]*  
Chih-Jung Hsu and Yen-Shin Lai   
, Taipei Tech., Taiwan

The main theme of this paper is to propose fast on-line optimal bandwidth search and controller tuning techniques for servo motor drives. The proposed controller tuning method derives the controller gains by searching the optimal bandwidth and identifying the inertia. The optimal bandwidth can be achieved before oscillation occurs. It will be shown the gains of speed controller of servo drives are tuned automatically to reflect the variation of load inertia. Experimental results derived from DSP-controlled PMSM servo drives will be shown. The results demonstrate on-line optimal bandwidth and auto gain tuning can be achieved without motor and load information in prior. These results fully support the developed techniques and claims.

**3:10PM***Open-loop Control for Permanent Magnet Synchronous Motor Driven by Square-wave Voltage and Stabilization Control [#319]*  
Daisuke Sato and Jun-ichi Itoh   
, Nagaoka University of Technology, Japan

In this paper, the open-loop control for permanent magnet synchronous motor (PMSM) driven by a square-wave voltage is proposed. The proposed control is able to transit from the PWM region to the square-wave voltage region via the over modulation region seamlessly. When the PMSM is driven by the square-wave voltage using the proposed control, the low-frequency torque vibration except 6th or 12th order harmonics occurs due to the transition to the square-wave voltage region. Therefore, a variable band pass filter (BPF) is introduced as the reduction method of the low- frequency torque vibration. The low-frequency component in the active current for the stabilization control is extracted by the filter. As an experimental result, the proposed method reduces the low- frequency vibration which can be represented for the torque by over 40%.

**3:35PM***A Robust Current Control Based on Proportional-Integral Observers for Permanent Magnet Synchronous Machines [#1120]*  
Milo De Soricellis, Davide Da Ru' and Silverio Bolognani   
, BOSCH GmbH, Germany; University of Padova, Italy

This paper deals with a novel robust current control scheme for Permanent Magnet Synchronous Machine based on the conventional cascade structure. The main idea is to substitute the commonly used decoupling network, which requires the precise knowledge of the system parameters in any working condition, with a more flexible and robust scheme. In particular, the traditional configuration is improved by mean of two proportional-integral observers which allow the preservation of the drive performances under the effects of disturbance. The improved robustness is achieved maintaining the reliable basic scheme with a pure proportional controller in the forward path with advantages in terms of design and tuning. A genetic algorithm is used to optimize the controller and the observer parameters. This multi-objective optimization leads to a good stability and an overall improved performance of the drive above all the operative range. The choice of the optimal solution is based on a novel fitness function which takes into account both dynamical features and disturbance rejection capabilities of the system. The effectiveness of the proposed control scheme is verified by mean of numerical simulations and experiments as well.

Medium Voltage Drives and High Power Drives

Monday, September 19, 1:30PM-4:00PM, Room: 101B, Chair: Shih-Chin Yang, Uday Deshpande

**1:30PM***A Pumpback Test Bench for IGCT-based 11MW/595Hz Variable-Frequency-Drives with 1.25MW Grid Capability [#1323]*  
Jie Shen, Stefan Schroeder, Fan Zhang, Kunlun Chen and Richard Zhang   
, GE Global Research, China; GE Global Research, Germany; GE Power Conversion, China

This paper presents a pumpback test bench for high-frequency high-power Variable-Frequency Drives with 11 MW power rating and up to 595 Hz load frequency. A Voltage Combiner concept is applied to allow a high-frequency output from the two IGCT bridges with minimum switching losses. The accordingly developed pumpback test bench applies a dc power coupling concept combined with a virtual grid that can achieve 11 MW test capability with only 1.25 MW facility transformer. By applying a virtual machine concept, the pumpback test can be conducted without the need of high-frequency machines, while the circulating power losses are minimized as well. The details about the virtual grid including the concept tradeoff, filter parameters and modulation schemes are presented. Moreover, design and installation guidelines for high-frequency components, especially the cables, are presented. The high-frequency high-power VFD and its pumpback test bench are both successfully built and experimentally validated at their rated operation points.

**1:55PM***Grounding Concept and Common-Mode Filter Design Methodology for Transformerless MV Drives [#1160]*  
Marius Mechlinski, Stefan Schroeder, Jie Shen and Rik W. De Doncker   
, GE Global Research Europe, Munich, Germany; GE Global Research China, Shanghai, China; E.ON ERC, RWTH Aachen University, Germany

Recently, the transformerless design of medium-voltage (MV) drives is an emerging design concept of variable-speed drives (VSD). Here, no dedicated feed transformer is used. The VSD is directly connected to the on-site facility transformer, where multiple other loads are connected as well. The benefits of such a transformerless VSD are the reduced total volume, weight, losses and system costs. In this publication, a suitable grounding concept and a generalized CM filter design methodology for transformerless MV drives is presented for the first time. Both the CM voltage injection to the grid and the CM voltage applied to the three machine terminals is considered. At the Point-of-Common-Coupling (PCC), the CM part of the grid harmonic standards can be met through a proper filter design. Since the converter-generated CM voltage could also cause issues on the machine-side, a novel design reference for the mitigation of bearing currents is applied. The introduced CM filter design methodology provides a suitable CM filter design for transformerless high-power medium- voltage converters. By this, the reliable transformerless operation of general purpose drives and retrofit applications is feasible.

**2:20PM***Utilisation of Series Connected Transformers for Multiple Active Rectifier Units [#802]*  
Wim van der Merwe, Mathieu Giroux, Pasi Tallinen and Jonas Wahlstrom   
, ABB Switzerland, Switzerland; ABB Finland, Finland

In many industrial systems the bulk of the power required for the process is being processed by medium-voltage (MV) high power variable speed drive systems. As the installed power of such MV drive systems increase, as a ratio of the available short circuit power, the relative power quality properties of these systems' AC-DC front ends become more critical. In high power drives several combinations of active rectifier units (ARUs) are possible, here the benefits of using several ARUs connected in parallel on the dc-side while utilizing a series connection of transformer primaries on the ac side are discussed.

**2:45PM***Common-Mode Voltage Limits for the Transformerless Design of MV Drives to Prevent Bearing Current Issues [#1153]*  
Marius Mechlinski, Stefan Schroeder, Jie Shen and Rik W. De Doncker   
, GE Global Research Europe, Munich, Germany; GE Global Research China, Shanghai, China; E.ON ERC, RWTH Aachen University, Germany

Recently, the transformerless design of medium-voltage (MV) drives is an emerging design concept of variable-speed drives (VSD). Here, no dedicated feed transformer is used. The VSD is directly connected to the on-site facility transformer, where multiple other loads are connected as well. The benefits of such a transformerless VSD are the reduced total volume, weight, losses and system costs. However, without a dedicated feed transformer the converter-generated common-mode (CM) voltage may generate harmful bearing currents that could yield serious bearing failures within a short time. For this reason, the suppression of bearing currents is a fundamental design aspect of VSD systems. In this publication, a comprehensive bearing current study highlights the two dominating bearing current mechanisms in VSD systems. Both mechanisms are caused by the converter- generated CM voltage applied to the machine terminals. Their physical understanding is used to define thresholds for the peak CM voltage and the maximum CM voltage slope to ensure the sufficient mitigation of bearing currents. The newly introduced CM voltage limits allow the development of a generalized CM filter design for transformerless VSDs which is the scope of another publication. By this, a reliable transformerless operation of general purpose drives and retrofit applications is feasible.

**3:10PM***A Robust Sensorless Start-up Method using Four Step Sequence for LCI system [#428]*  
Hyunsung An and Hanju Cha   
, Chungnam national university, Korea (South); Chungnam National University, Korea (South)

This paper proposes a new senseless start-up method using a closed loop current control and a flux estimator without position sensor, and it is composed of four step sequence. Step 1 is applied for detection of the initial rotor position, and an initial rotor position is estimated around 1% of accuracy within 150ms. Step 2 is applied for a stable start-up state from the standstill through a closed loop current control, and is up to 3% of the rated speed of synchronous machine. Step 3 and 4 are used in the range generating a sufficient back-emf, and employ a flux estimator. The flux estimator consists of field flux model and flux voltage model, and rotor position/speed are estimated by using a phase locked loop. Field flux model is applied up to 5% of the rated speed. Performance of the proposed start-up method is evaluated by Simpower/Matlab simulation at overall speed range. To verify a feasibility of the proposed method, a 5kVA prototype of load commutated inverter (LCI) system is implemented. Experimental results show the proposed sensorless start-up method works well in the overall sequence region.

**3:35PM***Virtual Voltage Source Control for 2x27 MVA Machine Test Bench [#1367]*  
Jie Shen, Jingkui Shi, Jun Zhu, Yulong Li, Bo Qu and Hongwu She   
, GE Global Research, China; GE Power Conversion, China

In this paper, a special control solution called Virtual Voltage Source is developed for no-load tests of induction machines. This concept is applied to a 2x27 MVA high-power machine test bench, where the test bench is requested to precisely characterize e.g. 3 MW machines at no-load currents. The developed Virtual Voltage Source thoroughly solves the stability issue of induction machines at low speed ranges. A set of optimizations is presented here that systematically improves the voltage precision of the test bench. Experimental results prove that the proposed concept achieves extremely low voltage and current unbalance, and low Harmonic-Voltage-Factor, verified by more than 100 induction machines.

Power Modules

Monday, September 19, 1:30PM-4:00PM, Room: 202C, Chair: Muhammad Nawaz, Douglas C Hopkins

**1:30PM***Performance Comparison of 10 kV-15 kV High Voltage SiC Modules and High Voltage Switch using Series Connected LV SiC MOSFET devices [#1703]*  
Kasunaidu Vechalapu and Subhashish Bhattacharya   
, NC State University, United States

The 10 kV to 15 kV SiC MOSFET and 15 kV SiC IGBT are state of the art high voltage (HV) devices designed by Cree Inc. These devices are expected to increases the power density of converters and are expected to replace 4.5 kV/6.5 kV Si IGBTs. However these are not commercially available. On the other hand low voltage (LV) 1.7 kV SiC MOSFET is commercially available and it is replacing existing 1.7 kV Si IGBT and it can meet immediate need of medium or high voltage (MV or HV) converter applications with series connection of these devices and can replace existing 4.5 kV/6.5 kV Silicon (Si) IGBT. Therefore, 10 kV-15 kV SiC modules and series connected 1.7 kV SiC MOSFET will be competing with each other for MV and HV converter applications. Hence, to explore the capability of low voltage SiC devices for MV or HV applications, a HV switch (10 kV-15 kV) using series connection of 1.7 kV/300 A SiC MOSFET modules has been investigated. For making HV switch using series connected 1.7 kV SiC MOSFET, a simple RC snubber method has been used for dynamic voltage sharing to offset the turn-off delays due to mismatch of device characteristics and/or gate signals. Experimental switching characterization with different values of RC snubbers has been carried out and a methodology has been outlined to find the optimal RC snubber which gives minimum voltage sharing difference, snubber losses and total semiconductor losses. In addition, experimental switching characterization of 10 kV-15 kV SiC modules is presented. Furthermore, performance comparison of HV 10 kV-15 kV SiC modules and HV switch using series connected 1.7 kV SiC MOSFETs is presented in this paper

**1:55PM***Development of an Ultra-high Density Power Chip on Bus (PCoB) Module [#1005]*  
Yang Xu, Iqbal Husain, Harvey West, Wensong Yu and Douglas Hopkins   
, North Carolina State University, United States

A traditional power module uses metal clad ceramic (e.g. DBC or DBA) bonded to a baseplate that creates a highly thermally resistive path, and wire bond interconnect that introduces substantial inductance and limits thermal management to single-sided cooling. This paper introduces a Power Chip on Bus (PCoB) power module approach that reduces parasitic inductance through an integrated power interconnect structure. The PCoB maximizes thermal performance by direct attaching power chips to the busbar, integrating the heatsink and busbar as one, and uses a dielectric fluid, such as air, for electrical isolation. This new power module topology features all planar interconnects and double-sided air cooling. Performance evaluations are carried out through comprehensive electrical and multi-physics simulation and thermal testing for a 1200V, 100A rated single-switch PCoB design. Fabrication and assembly processes are included. For the developed double- sided air-cooled module, 0.5 C/w thermal resistance and 8nH power loop parasitic inductance are achieved.

**2:20PM***Optimized Power Modules for Silicon Carbide MOSFET [#924]*  
Guillaume Regnat, Pierre-Olivier Jeannin, Jeffrey Ewanchuk, David Frey, Stefan Mollov and Jean-Paul Ferrieux   
, G2ELAB, France; Mitsubishi Electric RandD Centre Europe, France

An Integrated Power Board technology was used to construct a 3D power module. This packaging is suitable for use of WBG devices as it reduces the inductive parasitics to the strict minimum, with a 2nH loop inductance in our 1.2kV/80A SiC prototype using SiC MOSFETs. The packaging presents virtually no parasitics or necessity for slowing down the commutation, which is oscillation-free. The conducted emissions of the 3D module are more than halved in comparison to those of a bespoke wire-bonded, EMI-optimised module.

**2:45PM***An Improved Wire-bonded Power Module with Double-End Sourced Structure [#1151]*  
Miao Wang, Fang Luo and Longya Xu   
, the Ohio State University, United States

This paper proposes a wire-bonded design with a unique double-end sourced structure for multi-chip paralleled SiC power modules. The proposed design achieved a reduced power-loop inductance of 7.2 nH, while inheriting the advantages of the conventional wire-bond technology. More importantly, the symmetrical structure of the proposed design brought consistent performances to the paralleled devices. A 1200 V, 60 A SiC MOSFET half-bridge module (3 devices in parallel) was fabricated and tested for verification. It demonstrated suppressed voltage overshoot and improved current-sharing among the devices. In addition, the proposed layout exhibited lower radiation noises, which will cause less interference to the sensitive electronic devices. A converter level design is also presented to accommodate this unique module structure.

**3:10PM***An Initial Consideration of Silicon Carbide Devices in Pressure-Packages [#204]*  
Jose Angel Ortiz Gonzalez, Olayiwola Alatise, Li Ran, Philip Mawby, Pushparajah Rajaguru and Christopher Bailey   
, University of Warwick, United Kingdom; University of Greenwich, United Kingdom

Fast switching SiC Schottky diodes are known to exhibit significant output oscillations and electromagnetic emissions in the presence of parasitic inductance from the package/module connections. Furthermore, solder pad delamination and wirebond lift-off are common failure modes in high temperature applications. To this end, pressure packages, which obviate the need for wire- bonds and solder/die attach, have been developed for high power applications where reliability is critical like thyristor valves in HVDC line commutated converters. In this paper, SiC Schottky diodes in pressure-packages (press- pack) have been designed, developed and tested. The electrothermal properties of the SiC diode in press-pack have been tested as a function of the clamping force using different thermal contacts, namely molybdenum and Aluminum Graphite. Finite Element Simulations have been used to support the analysis.

**3:35PM***Effect of Junction Temperature Swing Durations on a Lifetime of a Transfer Molded IGBT Module [#139]*  
Choi Ui-Min, Blaabjerg Frede and Jorgensen Soren   
, Aalborg University, Denmark; Grundfos Holding A/S, Denmark

In this paper, the effect of junction temperature swing duration on the lifetime of a transfer molded Intelligent Power IGBT Module is studied and a relevant lifetime factor is modeled. A temperature swing duration dependent lifetime factor is defined based on 38 accelerated power cycling test results under 6 different conditions and it may improve a lifetime model for lifetime prediction of IGBT modules under various mission profiles of converters. The power cycling tests are performed by an advanced power cycling test setup which enables tested modules to be operated under more realistic electrical conditions during the power cycling test. The analysis of the test results and the temperature swing duration dependent lifetime factor under different definitions and confidence levels are presented.

Wireless Power Transfer I

Monday, September 19, 1:30PM-4:00PM, Room: 202B, Chair: Yaow-Ming Chen, Oscar Lucia

**1:30PM***An Inductive and Capacitive Integrated Couper and Its LCL Compensation Circuit Design for Wireless Power Transfer [#47]*  
Fei Lu, Hua Zhang, Heath Hofmann and Chris Mi   
, University of Michigan, United States; Northwestern Polytechnical University, China; San Diego State University, United States

This paper proposes a novel coupler structure for wireless power transfer, which takes advantage of both magnetic and electric fields. The coupler contains four metal structures, two each at the primary and secondary sides, which are capacitively coupled. Each structure consists of long strips of metal sheet to increase its self-inductance, which is then inductively coupled with the other three structures. The structures are vertically arranged, and the outer structures are larger than the inner ones to maintain the capacitive couplings. An external LCL compensation network is proposed to resonate with the coupler. The resonance provides conduction current flowing through each plate to establish magnetic fields, and displacement current flowing between different plates corresponding to electric fields. A 100W output power prototype is designed and implemented to operate at 1 MHz, and it achieves 73.6% efficiency from dc source to dc load at an air-gap distance of 18 mm. The contribution of this paper is to propose a concept to transfer power using magnetic and electric fields simultaneously. The potential application of this system is the charging of low power portable devices, such as laptops. After the coupler structure is optimized, it can be extended to higher power applications, such as vehicle charging.

**1:55PM***Design Procedure of Optimum Self-Inductances of Magnetic Pads in Inductive Power Transfer (IPT) for Electric Vehicles [#380]*  
Minhyuck Kang, Jongeun Byeon, Dong Myoung Joo, Minkook Kim and Byoung Kuk Lee   
, Sungkyunkwan University, Korea (South)

This paper presents a design process of inducing self-inductances for the lowest power losses of magnetic pads in inductive power transfer (IPT) system. The total losses of the magnetic pads caused by winding coil, ferrite core, and aluminum shield are numerically calculated and achieved by finite element analysis (FEA) simulation. By plotting the total power losses depending on the coil turns of each magnetic pad, the optimum primary and secondary inductances with the minimum power loss are derived. The validity of the design process is verified through the experimental results provided by a 3.3 kW laboratory prototype.

**2:20PM***Design high power and high efficiency inverter operating at 13.56MHz for wireless power transfer systems [#954]*  
Kien Trung Nguyen and Kan Akatsu   
, Shibaura Institute of Technology, Japan

This paper presents the proposed design of high power and high efficiency inverter for wireless power transfer systems operating at 13.56 MHz using multiphase resonant inverter and GaN HEMT devices. The high efficiency and the stable of inverter are the main targets of the design. The module design, the power loss analysis and the drive circuit design have been addressed. In experiment, a 3 kW inverter with the efficiency of 96.1% is achieved that significantly improves the efficiency of 13.56 MHz inverter. In near future, a 10 kW inverter with the efficiency of over 95% can be realizable by following this design concept.

**2:45PM***Improved Design Optimization Approach for High Efficiency Matching Networks [#1446]*  
Ashish Kumar, Sreyam Sinha, Alihossein Sepahvand and Khurram Afridi   
, University of Colorado Boulder, United States

Multistage matching networks are often utilized to provide voltage or current gains in applications such as wireless power transfer. Usually, each stage of a multistage matching network is designed to have a purely resistive input impedance and assumed to be loaded by a purely resistive load. This paper introduces an improved design optimization approach for multistage matching networks comprising L-section stages. The proposed design optimization approach explores the possibility of improvement in efficiency of the network by allowing intermediate stages to have complex input and load impedances. A new analytical framework is developed to determine the effective transformation ratio and efficiency of each stage for the case when input and load impedances may be complex. The method of Lagrange multipliers is used to determine the gain and impedance characteristics of each stage in the matching network that maximize overall efficiency. Compared with the conventional design approach for matching networks, the proposed approach achieves higher efficiency, resulting in loss reduction of up to 35% for a three-stage L-section matching network. The theoretical predictions are validated experimentally using a three-stage matching network designed for 10 MHz and 10 W operation.

**3:10PM***Efficiency Optimization Method of Wireless Power Transfer System with Multiple Transmitters and Single Receiver [#344]*  
Cheng Zhang, Deyan Lin and Shu Yuen Ron Hui   
, The University of Hong Kong, Hong Kong

In this paper, an analysis into the wireless power transfer system using inductive coupling with multiple transmitters and single receiver is presented. It is proved that, with certain total amount of input power from all of the transmitters, there is a maximal output power that can be delivered to the receiver. To achieve this optimal result, the electrical currents in all the transmitters shall be in-phase or 180-degree-out-of-phase. The magnitudes of the currents shall be controlled to match certain ratios. These ratios can be calculated from measurements in any known system. Experiments have been conducted to verify the theory in a wireless power transfer system with four transmitters and one receiver. The practical results match the simulated ones very well.

**3:35PM***Maximum Efficiency Tracking in Wireless Power Transfer for Battery Charger: Phase Shift and Frequency Control [#1071]*  
Devendra Patil, Marco Sirico, Lei Gu and Babak Fahimi   
, University of Texas at Dallas, United States; University of Naples Federico II, Italy

This paper presents a maximum efficiency point tracking algorithm for Wireless Power Transfer (WPT) to match the load impedance to that of the source impedance. Conventionally, the load is considered only resistive in the literature. In most of the applications the battery is the end load and the equivalent circuit of battery consists of resistive and reactive elements. Therefore, to improve the overall efficiency of the system, load impedance has to be matched with source impedance. In this paper, a maximum efficiency power tracking (MEPT) algorithm is presented to match source impedance to load impedance. Proposed algorithm varies both frequency and phase shift of the inverter output voltage to minimize input power, whereas output power is kept constant by a dc-dc converter. Battery voltage and current regulation are maintained by the output side dc-dc converter. A brief mathematical analysis is provided to verify the proposed concept. Further, a laboratory prototype with a power rating of 600W is developed, and results are provided to verify the effectiveness of the concept.

Monday, September 19, 5:30PM-7:00PM

Poster Session: Renewable and Sustainable Energy Applications

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Euzeli Santos Jr., Johan Enslin

**P101***Modeling, Parameterization, and Benchmarking of a Lithium Ion Electric Bicycle Battery [#495]*  
Weizhong Wang, Pawel Malysz, Khalid Khan, Lucia Gauchia and Ali Emadi   
, ECE department, McMaster University, Canada; ECE department, Michigan Tech University, United States

A lithium-ion battery from an electric bicycle conversion kit is tested and modeled using electrochemical impedance spectroscopy, and the hybrid pulse power characterization test (HPPC). Equivalent circuit model parameterizations are obtained from both time and frequency domain fitting and compared. Parameterization methods are described and a novel quadratic programmed-based two stage parameter fitting algorithm is presented to process and generate model parameters. Experimental data is applied to the proposed algorithm to assess fitting performance. The battery model is validated by real-life riding cycles. Additional electric bicycle benchmarking tests are performed to assess real-world battery performance under a variety of riding conditions and at different assistance levels. The brief correlation between tiredness and assistance levels is investigated.

**P102***Performance evaluation of a hybrid thermal-photovoltaic panel [#745]*  
Cristina Moscatiello, Chiara Boccaletti, Aderito Neto Alcaso, Carlos A. Figueiredo Ramos and Antonio J. Marques Cardoso   
, Sapienza University of Rome, CISE, Italy; Politechnic Institute of Guarda, CISE, Portugal; University of Beira Interior, CISE, Portugal

A theoretical and experimental analysis of a thermal-photovoltaic panel, whose purpose is to produce both electrical and thermal energy, has been performed. In order to achieve the main objective, the different components that constitute the thermal-photovoltaic panel have been studied and a simulation model of the proposed thermal-photovoltaic panel has been developed; then, the simulated values, based on the solar irradiance, the ambient temperature and the wind speed, have been compared with experimental data. The results are analyzed and discussed in the paper. In particular, such a validated model can be used to establish if and when it is more convenient to use a hybrid structure rather than two separate devices (PV only and thermal collector only).

**P103***On-line Wind Speed Estimation in IM Wind Generation Systems by Using Adaptive Direct and Inverse Modelling of the Wind Turbine [#1508]*  
Angelo Accetta, Maurizio Cirrincione, Giansalvo Cirrincione and Marcello Pucci   
, ISSIA-CNR, Italy; University of South Pacific (USP), Fiji, Fiji; University of Picardie, Jules Verne, France

This paper presents a neural network (NN) based wind estimator and related Maximum Power Point Tracking (MPPT) technique for high performance wind generator with induction machine. The target is to develop an MPPT system, embedding an adaptive virtual anemometer which is able to correctly estimate the wind speed even in presence of variations of the wind turbine characteristic, caused by aging or even damages. This paper proposes the use of the adaptive properties of feed- forward neural networks to address the on-line estimation of the wind speed even in case of slowly time- varying wind-turbine parameters. The method is inspired to the inverse adaptive control but it is used for parameter estimation and not for control purposes. Once the wind speed is estimated, the machine reference speed is then computed by the optimal tip speed ratio. For the experimental application, a suitably developed test set- up has been used, with a back-to-back configuration with two voltage source converters, one on the machine side and the other on the grid side.

**P104***Passivity-Based and Standard PI Controls Application To Wind Energy Conversion System [#1701]*  
Rui Gao, Rafael Cisneros, Iqbal Husain and Romeo Ortega   
, North Carolina State University, United States; Laboratoire des Signaux et Syst`emes, France

The controller design for wind energy conversion systems (WECS) is complicated considering the highly nonlinear properties of electric machines and power converters. Targeting at a controller for WECS, this article adopts a passivity based PI control (PI-PBC) method, to which the stability can be analytically guaranteed. Then, a comparative study between the proposed method and a standard PI is provided. The wind energy system consists of a wind turbine, a Permanent Magnet Synchronous Generator (PMSG), a pulse width modulation (PWM) rectifier, a dc load and an equivalent distributed energy storage device, which is formed with a dc source with internal resistor. The generator rotational velocity is regulated at maximum power point (MPPT) for the investigated wind turbine.

**P105***Evaluation of Circulating Current Suppression Methods for Parallel Interleaved Inverters [#760]*  
Ghanshyamsinh Gohil, Lorand Bede, Remus Teodorescu, Tamas Kerekes and Frede Blaabjerg   
, Aalborg University, Denmark

Two-level Voltage Source Converters (VSCs) are often connected in parallel to achieve desired current rating in multi-megawatt Wind Energy Conversion System (WECS). A multi-level converter can be realized by interleaving the carrier signals of the parallel VSCs. As a result, the harmonic performance of the WECS can be significantly improved. However, the interleaving of the carrier signals may lead to the flow of circulating current between parallel VSCs and it is highly desirable to avoid/suppress this unwanted circulating current. A comparative evaluation of the different methods to avoid/suppress the circulating current between the parallel interleaved VSCs is presented in this paper. The losses and the volume of the inductive components and the semiconductor losses are evaluated for the WECS with different circulating current suppression methods. Multi-objective optimizations of the inductive components have been also carried out. The design solutions, that are obtained using the optimization, have been compared on the basis of the volume of the inductive components and yearly energy loss for a given mission profile.

Poster Session: Smart Grid & Utility Applications

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Johan Enslin, Euzeli Santos Jr.

**P301***A Fast Dynamic Unipolar Switching Control Scheme for Single Phase Inverters in DC Microgrids [#692]*  
Nicolai Hildebrandt, Mandip Pokharel, Carl Ngai-Man Ho and Yuanbin He   
, Fraunhofer-Institut fur Solare Energiesysteme, Germany; University of Manitoba, Canada; City University of Hong Kong, Hong Kong

This paper presents the digital implementation of a boundary controller with unipolar switching characteristic for single phase voltage source full bridge inverters, which will be used as an interface between a low voltage DC microgrid and AC loads. This paper expands the second order switching surface control method for single phase inverters by unipolar switching with the use of a finite-state machine. Compared to bipolar switching, unipolar switching has the advantage of lower switching losses and filter size. Besides, the switching losses can be equally distributed among semiconductor switches compared to conventional three-level inverter switching scheme. The operating principles of proposed control scheme and mathematical derivation of the switching functions will be given. A 550 VA, 120 V, 60 Hz voltage source inverter (VSI) with a digital signal processor has been implemented to verify the theoretical predictions. Experimental results for steady state operation at different loading conditions show a tightly regulated output voltage, for large-signal disturbances the control is fast and precise.

**P302***A Novel Method of Optimizing Efficiency in Hybrid Photovoltaic-Grid Power System [#1598]*  
Liangliang Ren, Ke Jin, Ling Gu and Zhengshuo Wang   
, Nanjing University of Aeronautics and Astronaut, China

In this paper, a method of optimizing efficiency of hybrid photovoltaic-grid power system by changing dc bus voltage is introduced. The hybrid photovoltaic-grid power system composed of a solar cell, grid, DC bus, solar cell interface converter (Boost + full-bridge LLC resonant converter), grid interface converter (single-phase PWM rectifier) and load interface converter (half-bridge LLC resonant converter). By analyzing the loss of every interface converters in hybrid photovoltaic-grid power system, the relationship between the bus voltage and the efficiency of the whole system can be found out. To verify the loss analysis and the efficiency optimization method, 1kW hybrid photovoltaic-grid power system hardware was built in the lab. The experimental results verify the feasibility of the efficiency optimization method.

**P303***A Novel Autonomous Control Scheme for Parallel, LCL-Based UPS Systems [#404]*  
Mohammad Bani Shamseh, Atsuo Kawamura and Teruo Yoshino   
, Yokohama National University, Japan; Toshiba Mitsubishi-Electric Industrial Systems, Japan

This paper proposes a novel autonomous control scheme for equal load current distribution between n parallel-connected, LCL-based, three phase UPS units. The control is based on varying the capacitor reference voltage of each inverter as a function of its own output current, without exchanging information between the inverters. The load voltage is maintained fixed at the specified reference value. The control method is fast, precise and robust against load variations. Capacitor voltage and capacitor current are used in a dual-loop control at each inverter. The validity of the proposed method is verified by simulation and experiments on a system of two 5-kVA parallel inverters.

**P304***Harmonic Components Based Protection Strategy for Inverter-Interfaced AC Microgrid [#571]*  
Chen Zhi, Pei Xuejun and Peng Li   
, Huazhong University of Science and Technology, China

In the inverter-interfaced AC microgrid (IIAM), when a short-circuit fault occurs at the distribution line, the output fault current of inverter is commonly limited to two times over its rated current due to the limited overcurrent capacity of power electronic device. Therefore, the conventional overcurrent protection principle cannot be applied to IIAM. Aiming at addressing this issue, a new protection method based on the low harmonics components is proposed in this paper. Through injecting a certain proportion of fifth harmonics to the fault current, the protection device can detect the fault according to the low harmonics components extracted by the digital relay (DR). This scheme does not rely on the large fault current. Therefore, some limitations of the traditional overcurrent protection are avoided. The corresponding experiments were carried out with two 10kVA parallel-connected inverters supply system, and the results proved the feasibility of this approach.

**P305***Adaptive Virtual Inertia Control of Distributed Generator for Dynamic Frequency Support in Microgrid [#732]*  
Jianhui Meng, Yi Wang, Chao Fu and Hui Wang   
, North China Electric Power University, China

The distributed generator based on power electronic converters has no inherent inertial response like that from the rotating mass of the conventional synchronous generator. The control scheme of Virtual Synchronous Generator (VSG) is anticipated to improve the distributed generator system stability by imitating the behavior of the synchronous generator including the system inertia. Unlike a real synchronous generator, the equivalent inertia of the distributed generator using VSG can be controlled in a wide range with the system frequency variation. In order to explore this feature for providing a fast and smooth inertial response, a flexible virtual synchronous generator control (FVSG) strategy with adaptive inertia is proposed. By fully considering the relationship between system inertia and frequency fluctuation rate, a calculation method adopting a function of the frequency change rate to achieve an adaptive inertia coefficient is presented and introduced to the VSG control. A simulation system using Matlab/Simulink is implemented to validate the proposed FVSG control strategy on improving the system dynamic frequency performances.

**P306***Interleaved Hybrid Boost Converter with Simultaneous AC and DC Outputs for Microsource Applications [#906]*  
Amrita Sharma, Pramod Bura, R. K. Singh and Ranjit Mahanty   
, Indian Institute of Technology (BHU), India

This paper proposes an interleaved hybrid boost converter (IHBC) with simultaneous AC and DC outputs for microsource applications. The proposed IHBC is realized by interleaving two boost converters and replacing the control switch of one of the boost converters with H-bridge voltage source inverter network. The IHBC gives DC and AC output simultaneously from a single DC input and has the property that summation of modulation index (m) and the steady state duty ratio (D) may be more than one unlike the conventional hybrid converters. Thus, the proposed IHBC is capable of giving high DC and AC voltage gainand has inherent shoot through protection capability. A suitable modified unipolar sinusoidal pulse width modulation (SPWM) technique is discussed and a feedback loop is designed to regulate the DC output voltage. Steady state and dynamic modeling is carried out to exhibit the advantages of the IHBC. The proposed IHBC is validated for DC microsource (solar cell) through mathematical modeling, simulation, and experimental results.

**P307***Robust Inverter Control Design in Islanded Microgrids Using $$-Synthesis [#1532]*  
Mohsen Azizi and S. Ali Khajehoddin   
, Michigan Technological University, United States; University of Alberta, Canada

In this paper, a robust controller is designed to control the output voltage of an inverter with an LC type output filter in an islanded microgrid. The proposed controller includes a local droop controller, as well as a robust controller that is designed based on the $\mu$-Synthesis technique. The performance of the designed controller is proven to be robust to the uncertainties which include the time delay and parameter changes during the operation of the inverter, while the resonant oscillations are properly damped to meet the standard requirements. The proposed controller only relies on output feedback which alleviates the need for extra sensors to measure the states of the system. Simulation are conducted to verify the robust performance of the designed controller in the presence of parameter uncertainties and time delay.

**P308***Economic Analysis of a Regional Coordinated Microgrids System Considering Optimal PEVs Allocation [#1643]*  
Liangle Xiao, Changsong Chen, Shanxu Duan, Hua Lin, Yawei Wang and Guozhen Hu   
, Huazhong University of Science and Technology, China; Hubei Polytechnic University, China

In this paper, the economic analysis of a regional coordinated Microgrids system (RCMS) considering the allocation model of plug-in electric vehicles (PEVs) is proposed. Such a system is made up of a Residential Microgrid (RMG) and an Industrial Microgrid (IMG), and the two microgrids are already configured with optimized wind turbines and photovoltaic arrays. In this model, the PEVs are served as a mobile energy storage system, purchasing energy from RMG at off-peak times when electricity prices are low, and selling to the IMG when electricity prices are high. To minimize the total cost of RCMS, the optimal number of PEVs is figured out by means of improved particle swarm optimization (IPSO) algorithm. To research the factors affecting optimal PEVs number and cost of the system, the relationship of PEVs charging and discharging price is deeply analyzed. The proposed smart optimal allocation model is tested with case one and case two. The simulation results show that the total cost of the system is effectively reduced adopting the proposed model.

**P309***Design of a Cooperative Voltage Harmonic Compensation Strategy for Islanded Microgrids Combining Virtual Admittances and Repetitive Controllers [#1666]*  
Cristian Blanco, Francesco Tardelli, David Diaz, Pericle Zanchetta and Fernando Briz   
, University of Oviedo, Spain; University of Nottingham, United Kingdom

Non-linear loads (NLLs) in three-phase systems are known to produce current harmonics at -5, 7, -11, 13, ... times the fundamental frequency; harmonics of the same frequencies are induced in microgrid voltage, reducing therefore the power quality. Dedicated equipment like active power filters can be used to compensate the microgrid harmonics; alternatively, each distributed generation (DG) unit present in the microgrid can be potentially used to compensate for those harmonics. The use of the virtual admittance concept combined with a PI-RES control structure has been recently proposed as a harmonic compensation sharing strategy when multiple DGs operate in parallel. The drawback of this methodology is that a large number of RES controllers might be required to compensate for all harmonic components induced by NLLs. This paper proposes the combined use of virtual admittance control loop and repetitive controller (RC) for harmonic compensation. The main advantage of the proposed method is that only one RC is required to compensate for all the harmonic components, significantly reducing the computational burden and the design complexity.

Poster Session: Transportation Electrification Applications

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Jin Wang, Yaosuo "Sonny" Xue

**P501***EMI Reduction Technology in 85 kHz Band 44 kW Wireless Power Transfer System for Rapid Contactless Charging of Electric Bus [#641]*  
Tetsu Shijo, Kenichirou Ogawa, Masatoshi Suzuki, Yasuhiro Kanekiyo, Masaaki Ishida and Shuichi Obayashi   
, Toshiba Corporation, Japan

A 44 kW wireless power transfer (WPT) system is being developed for rapid contactless charging in an electric bus in the 85 kHz band, the candidate frequency for a wireless charging system for light-duty vehicles that is currently undergoing standardization. For field operation of this WPT system using the 85 kHz band in Japan, permission for use as industrial facilities emitting radio waves is required under the Radio Act. A two-channel WPT system with currents of opposite phase in the two transmit pads of the channels is introduced to reduce radiated emissions to within the Radio Act limits of electromagnetic radiation disturbance by cancelling the emission from each channel. Then, the diagonal placement of the transmit pads for the two channels is proposed to avoid the interference between the two channels where the interference couplings become null. Finally, the measured emission of the 44 kW WPT system in a 10 m anechoic chamber is shown.

**P502***Design and Characterization of a Meander Type Dynamic Inductively Coupled Power Transfer Coil [#669]*  
Ugaitz Iruretagoyena, Irma Villar, Haritza Camblong, Asier Garcia-Bediaga and Luis Mir   
, IK4-Ikerlan, Spain; University of the Basque Country, Spain

The aim of this paper is to present an alternative coil topology for ICPT (Inductively Coupled Power Transmission) links, called meander type coil, specifically for dynamic charging. The analysis is carried out using FEM software FLUX supported by Matlab. The goal is to design an inductive link in such a way that the coupling keeps constant while the receiver part is moving along the track, in order to make the converter and the control easier to implement. Different geometrical parameters are analyzed and compared to obtain the highest efficiency value.

**P503***Design of S/P Compensated IPT System Considering Parameter Variations in Consideration of ZVS Achievement [#1365]*  
Yusheng Zhang, Qianhong Chen, Xiaoyong Ren, Siu-Chung Wong, Zhiliang Zhang and Wei Hua   
, Nanjing University of Aero. and Astro., China; Hong Kong Polytechnic University, Hong Kong; Southeast University, China

Due to variations of misalignment and clearance, the parameters of the contactless transformer (CT) change a lot, creating great challenge in the design and control of the inductive power transfer systems. In this paper, the characteristics of a S/P compensated resonant converter is analyzed by introducing relative self-inductance coefficient and relative mutual-inductance coefficient to describe the parameter variations for CT. Based on the voltage gain and input impedance analysis, the voltage gain value at the intersection point and the inductive region of the input impedance are found. Furthermore, a fully tuned point is selected fulfilling zero voltage switching (ZVS) condition for the full-parameter ranges of load and CT. A 7.5 kW prototype with constant frequency control is developed and fabricated to verify the analysis.

**P504***Coasting Control of EV Motor Considering Cross Coupling Inductance [#873]*  
Heekwang Lee, Bonkil Koo and Kwanghee Nam   
, POSTECH, Korea (South)

Coasting is a fuel-saving driving mode that is usually active when the vehicle slows down. It is understood as the rolling of a vehicle without any positive or negative traction force. In an electric vehicle, coasting can be achieved by letting the q-axis current to be set to zero. However, braking action often occurs at high speeds when the gas pedal is tipped off. That is, negative torque is produced while the q-axis current is equal to zero. Such a braking torque reduces the coasting distance. To prevent such undesirable braking, a positive q-axis current command is injected in practice. In this paper, a cross-coupling inductance, Lqd, is studied as a main cause for the braking torque. If it is present, torque can be developed by only the d-axis current. Further, it grows quickly as the speed increases. The problem can be solved by shifting the angle of the reference frame. The compensation angle is analytically derived using two different methods. The proposed compensation method was demonstrated effectively by simulation and experiments.

**P505***Analysis and Comparison of Single Inverter Driven Series Hybrid System [#969]*  
Yongjae Lee, Kahyun Lee and Jung-Ik Ha   
, Seoul National University, Korea (South)

This paper proposes and analyzes the novel single inverter driven series hybrid system. Conventional series hybrid power transfer system features the high- efficiency thanks to the variable torque and speed operation of the internal combustion engine. The increment in cost is, however, still remained as a hurdle. The proposed single inverter driven series hybrid structure reduces two high power inverters into one with low current rating. It also does not require rigid power transferring parts such as axles and enables flexible configuration. This paper presents the comparison of the proposed system with conventional parallel and series hybrid system. The characteristics of the electric system which uses single inverter are also analyzed. The feasibility and operation of the proposed structure are verified through the simulation.

**P506***Control Strategy for a Modified Cascade Multilevel Inverter with Dual DC Source for Enhanced Drivetrain Operation [#1178]*  
Maciej Bendyk and Patrick Chi Kwong Luk   
, Cranfield University, United Kingdom

This paper presents a new control strategy for a modified cascade multilevel inverter used in drivetrain operations. The proposed inverter is a three-phase bridge with its dc link fed by a dc source (battery), and each phase series- connected respectively to an H-bridge fed with a floating dc source (ultracapacitor). To exploit the potentials of the inverter for enhanced drivetrain performance, a sophisticated yet efficient modulation method is proposed to optimise energy transfer between the dc sources and with the load (induction motor) during typical operations, and to minimise switching losses and harmonics distortion. Detailed analysis of the proposed control method is presented, which is supported by experimental verifications.

**P507***An Investigation of DC-Link Voltage and Temperature Variations on EV Traction System Design [#1254]*  
Nan Zhao, Rong Yang, Nigel Schofield and Ran Gu   
, McMaster University, Canada

DC-link voltage and temperature variations are critical issues when designing an electric vehicle (EV) traction system. The paper presents an assessment of electric vehicle power-train options based on the Nissan Leaf vehicle, which is taken as a benchmark system providing same validation for the study. The Nissan Leaf traction machine is evaluated and performance assessed by considering DC-link voltage and temperature variations. An alternative traction machine design is proposed to satisfy the specification. The vehicle power-train is then modified with the inclusion of a DC/DC converter between the battery pack and DC-link to maintain the traction system DC-link voltage near constant. Additionally, inclusion of a supercapacitor system presents a much tighter input voltage specification but still doesn't completely eliminate the issue. Finally, installing a DC/DC converter to mitigate the faulted operation of electric machine drive is reported.

**P508***Compact and High Power Inverter for the Cadillac CT6 Rear Wheel Drive PHEV [#31]*  
Mohammad Anwar, Mehrdad Teimor, Peter Savagian, Ryuichi Saito and Takeshi Matsuo   
, General Motors, United States; Retired from General Motors, United States; Hitachi Automotive, Japan

Electric drive system for the Cadillac CT6 plug-in hybrid electric vehicle Electric drive system for the Cadillac CT6 plug-in hybrid electric vehicle Electric drive system for the Cadillac CT6 plug-in hybrid electric vehicle Electric drive system for the Cadillac CT6 plug-in hybrid electric vehicle

Poster Session: Power Converter Topologies

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Pradeep S. Shenoy, Leon M Tolbert

**P701***Quadratic Boost A-Source Impedance Network [#553]*  
Yam Siwakoti, Andrii Chub, Frede Blaabjerg and Dmitri Vinnikov   
, Aalborg University, Denmark; Tallinn University of Technology, Estonia

A novel quadratic boost A-source impedance network is proposed to realize converters that demand very high voltage gain. To satisfy the requirement, the network uses an autotransformer where the obtained gain is quadratically dependent on the duty ratio and is unmatched by any existing impedance source networks and normal dc-dc converters with coupled magnetics at the same duty ratio and turns ratio. The term Quadratic Boost A-Source indicates its quadratic varying gain in the operating principle of the converter. The proposed converter draws a continuous current from the source and suits for many types of renewable sources. This capability has been demonstrated by mathematical derivation and proven in experiments with a single-switch 200 W, 40 kHz dc-dc converter.

**P702***Analysis and Design of a Switched-Capacitor Step-Up Converter for Renewable Energy Applications [#589]*  
Ricardo Mota-Varona, Ma. Guadalupe Ortiz-Lopez, Jesus Leyva-Ramos and Diego Langarica-Cordoba   
, Instituto Potosino de Inv Cient y Tec, Mexico; Universidad Politecnica de SLP, Mexico

In this work, a complete study of the dynamical behavior of a class of switched- capacitor converters is carried out. The relationships between voltages, currents and duty ratio are given, as well as the corresponding ripples on the inductor currents and capacitor voltages that allow the proper selection of elements of the converter. The linear switching, nonlinear average and linear average models are derived. Transfer functions of possible variables to be used for control purposes are analyzed too. Experimental results in a 150 W converter are shown to verify the theoretical results given within.

**P703***Non-Isolated High-Step-Up Resonant DC/DC Converter [#740]*  
Ying Huang, Chun-Yuen Lai, Song Xiong, Siew-Chong Tan and Shu Yuen (Ron) Hui   
, The University of Hong Kong, Hong Kong

A non-isolated high-step-up resonant DC/DC converter made up of a resonant inverter and a passive switched-capacitor(SC) rectifier, is proposed in this paper. The proposed converter is free of transformer and coupled-inductor. Thus, issues related to the leakage inductance and the large volume magnetic component caused by large turn's ratio of high-voltage-gain applications, are avoided. Besides, as the converter contains only one active switch, its control is simple. Second harmonic voltage across the switch is attenuated to provide low voltage stress for the active switch and a higher voltage gain of the converter. The voltage gain of the converter is not achieved by a single stage, but by the gain product of the resonant inverter and SC rectifier. A prototype with input voltage 6 V, 500 kHz switching frequency, 50% duty cycle, is constructed to validate the performance of the proposed converter. The voltage gain of the prototype is over 33 times and the achievable efficiency is close to 90% under a wide load resistance range.

**P704***Three Level DC-DC Converter Based on Cascaded Dual Half-Bridge Converter for Circulating Loss Reduction [#162]*  
Zhiqiang Guo and Kai Sun   
, Tsinghua University, Beijing, China

An improved two-half-bridge cascaded three-level (TL) DC-DC converter with reduced circulating current is proposed in this paper. The converter contains two transformers but without clamping diodes or flying capacitors. The rectifier stage is composed of four diodes and four windings of the two transformers. Because of the proper sequence of the windings, the circulating currents on the primary side of the transformers decay to zero during the freewheeling period. Although the circulating current is reduced, the primary switches still achieve zero voltage switching (ZVS). Furthermore, the proposed converter can reduce the current ripple of the filter inductor, leading to a reduction in output filter inductance. Due to the advantages mentioned above, the proposed converter can meet the high efficiency, low size, and light weight requirements. Lastly, a 1kW prototype is built to verify the performance of the proposed converter.

**P705***Current-fed Converters with Switching cells [#381]*  
Zeeshan Aleem and Moin Hanif   
, University of Cape town, South Africa; University of Cape Town, South Africa

In this paper, new full bridge and half bridge current-fed converters with switching cells are proposed. Full bridge current-fed converters have several key applications in industry where high gain is required. However, conventional current-fed converters face some significant drawbacks: 1) current commutation problem of input inductor in case of dead time between the top switches of first and second leg. 2) High voltage spikes occur due to the leakage inductance of the transformer. In order to address these problems current-fed full and half bridge converters with switching cells are proposed and phase shift control scheme is employed to achieve zero current switching for the all the active switches. Theory, simulations and experimental results are presented to verify the working of the proposed converters.

**P706***Analysis of LCLC Resonant Converters for High-voltage High-frequency Applications [#419]*  
Bin Zhao, Gang Wang and Gerard Hurely   
, University of Chinese Academy of Sciences, China; Space Travelling-wave Tube Research Center, China; Power Electronics Research Center, NUI, Galway, Ireland

this paper proposes a novel LCLC full-bridge resonant converter with ZCS and ZVS for high-voltage high-frequency applications. In this operating model, both of ZCS and ZVS can be achieved and the switching losses can be reduced to a minimum. The proposed converter adopts the parasitic parameters of the step- up voltage transformer and one other serial capacitor is needed to form the resonant tank. Compared with other resonant converters, where only ZCS or ZVS can be achieved, the proposed working model can increase conversion efficiency with soft-switching features. Finally, A 40 V input, 4800 V output and 300 W prototype with 500 kHz switching frequency was built to verify the benefits of the proposed converter. The achieved efficiency of the converter peaked at 96.7%.

**P707***A Novel Constant Voltage Primary-side Regulator Topology to Eliminate Auxiliary Winding [#595]*  
Yongjiang Bai, Wenjie Chen, Xiaoyu Yang, Xu Yang and Guangzhao Xu   
, Xi'an Jiaotong University, China; Silergy Corp., China

Primary-side regulation (PSR) scheme is widely used in low-cost and low power applications such as cell phone charger and LED lighting. Generally, an auxiliary winding in the conventional flyback converter is used for both power supplier and feedback sensing. With the increase of labor cost, the transformer needs to be produced automatically. So the transformer architecture should be designed as simple as possible to meet automatic production requirement. In this paper, a novel constant voltage primary-side regulator topology is proposed to eliminate the auxiliary winding. On one hand, the controller is built in self- powered function. On the other hand, a dedicated scheme is used to guarantee the accurate output voltage sensing. Meanwhile, new technology is presented in detail to obtain better EMI performance. To verify the efficiency of the proposed constant voltage primary-side regulator topology, a dedicated constant voltage regulator integrated in a power IC is fabricated. The experimental results demonstrated that the prototype based on the proposed integrated chip has excellent regulation and EMI performance without auxiliary winding of the transformer.

**P708***Single-Phase/-Switch Voltage-Doubler DCM SEPIC Rectifier with High Power Factor and Reduced Voltage Stress on the Semiconductors [#617]*  
Paulo Junior Silva Costa, Carlos Henrique Illa Font and Telles Brunelli Lazzarin   
, Federal University of Santa Catarina, Brazil; Federal University of Technology - Parana, Brazil

This paper proposes a single-phase SEPIC rectifier that works in discontinuous conduction mode (DCM). The proposed rectifier employs a three- stage switch and a voltage-doubler structure. Hence, it works as two half- wave rectifiers with the output voltages series-connected and thus it provides a higher voltage gain. The paper presents the theoretical analysis of the proposed structure and it also discusses a comparison between the proposed converter and the classic SEPIC rectifier, which shows that the proposed converter might either provide reduced voltage stress on the semiconductors to the same output voltage level, or it might supply double the gain in the output voltage with the same voltage stress. In both cases, the novel rectifier maintains the high power factor with no current control from the classical DCM SEPIC rectifier. The study was verified by experimental results obtained with a prototype of 1000 W, 220 V at input voltage, 400 V at output voltage and 50 kHz at switching frequency. Testes at rated power provided a current THD equal to 3.2%, a power factor of 0.9992 and an efficiency of 94.34%.

**P709***Z-Source Resonant Converter with Power Factor Correction for Wireless Power Transfer Applications [#628]*  
Nomar S. Gonzalez-Santini, Hulong Zeng, Yaodong Yu and Fang Zheng Peng   
, Michigan State University, United States

In this paper the Z-source converter is introduced to power factor correction (PFC) applications. The concept is demonstrated through a wireless power transfer (WPT) system for electric vehicle battery charging, namely Z-source resonant converter (ZSRC). Due to the Z-source network (ZSN), the ZSRC inherently performs PFC and regulate the system output voltage simultaneously, without adding extra semiconductor devices and control circuitry to the conventional WPT system such as conventional PFC converters do. In other words, the ZSN can be categorized as a family of the single stage PFC converters. In addition, the ZSN is suitable for high power applications since it is immune to shoot-through states, which increases reliability and adds a boost feature to the system. The ZSRC-based WPT system operating principle is described and analyzed in this paper. Simulations, and experimental results based on a 1-kW prototype with 20-cm air gap between the system primary and secondary side are presented to validate the analysis, and demonstrate the effectiveness of the ZSN in the PFC of the WPT system.

**P710***A High-Power-Density Single-Phase Inverter with Pulse Current Injection Power Decoupling Method [#264]*  
Xiaofeng Lyu, Yanchao Li, Ngoc Dung Nguyen, Ze Ni and Dong Cao   
, North Dakota State University, United States

This paper presents high-power-density inverter with pulse current injection power decoupling method. In order to reduce the dc-link capacitor significantly, dc-link current is fully analyzed with double Fourier method in theory. Compared with the traditional 2nd harmonic power decoupling method, the pulse current injection method considers not only 2nd order harmonic but also the higher order harmonics. As a result, it can further reduce the dc-link capacitor value. The relationship between the dc-link capacitor value and different order harmonics has been investigated and analyzed. It shows that when dc-link capacitor value is reduced to one critical value, traditional 2nd harmonic power decoupling method is limited. Finally, one novel pulse current injection method is proposed and verified by simulation.

**P711***Hybrid Multilevel Converter based on Flying Capacitor and Extended Commutation Cell [#412]*  
Sjef Settels, Gabriel Tibola and Erik Lemmen   
, Eindhoven University of Technology, Netherlands

The extended commutation cell (ECC) is a promising switching cell that allows for bidirectional energy transport in two orthogonal directions throughout the cell. By combining the ECC with a flying capacitor (FC) converter topology, a multilevel converter with a high number of levels can be assembled. This paper presents the analysis of a hybrid converter composed of an arbitrary number of ECCs and a flying capacitor. A 3 kW inverter configuration consisting of two ECCs and a flying capacitor is designed and verified by simulation. The result is a 12-level hybrid converter with equidistant output levels and closed loop control of the capacitor voltages of the ECC and FC. The required number of switches decreases from 22 in a 12-level FC converter to 12 in the proposed hybrid configuration, with the addition of two inductors.

**P712***A Novel Hybrid Five-Level Voltage Source Converter Based on T-Type Topology for High-Efficiency Applications [#223]*  
Shuai Xu, Jianzhong Zhang, Xing Hu and Yongjiang Jiang   
, Southeast University, China

A novel hybrid five-level voltage source converter for high-efficiency applications is presented and investigated in this paper, and the topology configuration is based on the upgrade of three-level T-type converter and two- level converter. Compared with traditional stacked multilevel converter and flying capacitor multilevel converter, this hybrid multilevel converter generates desired staircase voltage levels with a reduced number of power devices and isolated drivers. It has nine redundant switching state combinations in hybrid five-level converter, which makes it easy to balance the flying capacitor voltage and realize fault-tolerant operation. A simple control strategy based on phase disposition PWM method is presented for the proposed hybrid converter, in order to generate desired levels while control the flying capacitor voltage. The performance of the hybrid multilevel converter is investigated in MATLAB/Simulink under various operating conditions. The effectiveness of the proposed hybrid multilevel converter is validated by experimental platform.

**P713***Flying-Capacitor-Clamped Five-Level Inverter Based on Switched-Capacitor Topology [#333]*  
Chen Cheng and Liangzong He   
, Xiamen University, China

This paper proposed a novel flying-capacitor-clamped five-level inverter based on bridge modular switched-capacitor topology. The inverter features the switched-capacitor circuit with step-up ability and the multilevel inverter circuit with flying-capacitor-clamped performance. With the composite structure, the number of components is cut down compared with the topology of conventional multilevel inverter, the voltage stress of most switches can be reduced, and part of switches can be operated under line voltage frequency. Hence, the potential of system efficiency and power density is released due to embed switched-capacitor circuit. Also, the cost is reduced obviously. More important, the optimized carrier-based phase disposition (PD) PWM method is employed as control strategy, the capacitor voltage can realize self-balance and quality of output waveform is improved significantly. After simulation, the prototype is built to validate the correctness and practicability of the analysis.

**P714***Cascaded Three-phase Quasi-Z Source Photovoltaic Inverter [#383]*  
Zhiyong Li, Weiwei Zhang, Yougen Chen and Xingyao He   
, Central South University, China

With the applications and development of photovoltaic micro grid within the framework of low voltage distribution network, the research on topology, output quality and costs of three-phase grid-connected photovoltaic inverter has become one of the recent focus. A multiplexed inverter topology cascaded by line voltage is proposed, which composes three modules: PV panel, quasi-z source network and three-phase inverter. Through an analysis of the function feature of established mathematical model, an improved dual-loop control system is proposed. To demonstrate the effectiveness of the topology and control system, a simulation model is built. Voltage boost is added in the improved dc side, where 180V PV input voltage of each module can realize 380V direct grid-connection without transformer. Costs and switch frequency are decreased, and harmonic content of grid current is merely 2.09%. The proposed control methodology is fit in three- phase grid-connection generation system with new energy.

**P715***Hybrid Three-Phase Four-Wire Inverters Based on Modular Multilevel Cascade Converter [#769]*  
Filipe Bahia, Cursino Jacobina, Italo Silva, Nady Rocha, Bruno Luna and Phelipe Rodrigues   
, DEE UFCG, Brazil; DEE UFPB, Brazil

This paper presents two hybrid four-leg inverters that can be be employed in unbalanced three-phase systems. The proposed topologies are based on a modular multilevel cascade converter (MMCC) with double-star chopper cells (DSCC) associated to a conventional two-level (2L) leg. A comparative analysis in terms of the harmonic distortion and semiconductor power losses between the proposed configurations and others four-leg inverters is presented. Additionally, a voltage balancing algorithm of the floating DC capacitors of the DSCC leg is presented to ensure the energy balance. At last, to investigate the proposed system and control strategy, simulation and experimental results are presented.

**P716***Hybrid Nine-Level Single-Phase Inverter Based on Modular Multilevel Cascade Converter [#771]*  
Filipe Bahia, Cursino Jacobina, Italo Silva, Nady Rocha, Bruno Luna and Phelipe Rodrigues   
, DEE UFCG, Brazil; DEE UFPB, Brazil

This paper presents a hybrid single-phase inverter based on a modular multilevel cascade converter (MMCC) with double-star chopper cells (DSCC). The proposed inverter is constituted by one five-level (5L) DSCC leg and one two-level (2L) leg, providing a nine-level voltage at its output. For this, a hybrid modulation technique is employed, allowing the DSCC leg to operate at the switching frequency and the 2L leg to operate at the fundamental frequency, which reduces switching losses. Compared to other nine-level cascaded H-bridge inverters, the proposed topology requires only one isolated voltage source and generates less losses in the semiconductors. At last, to investigate the proposed system and control strategy, simulation and experimental results are presented.

**P717***Multilevel Converter Based on Cascaded Three-Leg Converters With Reduced Voltage and Current [#772]*  
Edgard Fabricio, Cursino Jacobina, Nady Rocha, Lacerda Rodrigo and Correa Mauricio   
, IFPB, Brazil; UFCG, Brazil; UFPB, Brazil

In this paper, modularity concept using standard three-leg converters is addressed. Three-phase cascade converters composed by standard three-leg converters are investigated. They are composed of three, nine, twenty-one or n three-leg converters. It permits to reduce levels of currents and voltages on switches compared to conventional three-phase module or cascaded Hbridge converter. Other advantages include a modular structure that leads to convenient construction, easy maintenance and extension to higher voltage and current levels. Dynamic model is developed, and a PWM strategy is designed to converter command accordingly with the control reference generated voltage. Comparisons in terms of harmonic distortion and semiconductor power losses, between proposed and conventional cascade H-bridge have been carried out. Simulation and experimental results are presented.

**P718***Operation of modular matrix converter with hierarchical control system under cell failure condition [#876]*  
Yushi Miura, Tomoaki Yoshida, Takuya Fujikawa, Takuma Miura and Toshifumi Ise   
, Osaka University, Japan

A modular multilevel matrix converter (MMMxC) has nine arms and each of the arms is composed of H-bridge cells connected in cascade. It can be applied to high voltage ac-ac converters for variable speed wind turbines and motor drives. In this paper, employment of a hierarchical control system for the MMMxC is first considered to distribute computational burden among processors and simplify hardware implementation. The influence of the time delay due to communication of controllers on performance is investigated by numerical simulation. Second, the control scheme for the operation under a cell failure condition is proposed. In the case that a cell breaks down, the operation is continued not only by shorting the faulty cell with an external mechanical switch but by increasing capacitor voltage of the other cells in the same arm. Moreover, a constraint on output voltage of the arm that has the faulty cell is added to avoid occurrence of short circuit of arms. These changes of control schemes are easily implemented because of employing the control system with the hierarchical structure and a voltage space vector modulation control scheme without circulating current control. The proposed control scheme is verified by simulation.

**P719***The Delta-Connected Cascaded H-Bridge Converter Application in Distributed Energy Resources and Fault Ride Through Capability Analysis [#931]*  
Ping-Heng Wu, Yuh-Tyng Chen and Po-Tai Cheng   
, National Tsing Hua University, Taiwan

There are two unbalanced conditions for cascaded converter in Renewable Energy Source (RES) system. One is from the different output power of RES in bridge cells, and the other is grid voltage unbalanced fault. This paper presents a flexible voltage control technique of Modular Multilevel Cascaded Converter with single-delta bridge cells (MMCC-SDBC) in the RES system for maintaining the stable operation under the unbalanced conditions. Moreover, the comparison of the fault ride through capability between MMCC with Single Star Bridge Cells (MMCC- SSBC) and MMCC-SDBC is addressed in this paper. The laboratory test results are given to verify the proposed method and the analysis.

Poster Session: Control, Modelling and Optimization of Power Converters

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Pericle Zanchetta, Luca Solero

**P901***Dual Sequence Current Control Scheme Implemented in DSRF with Decoupling Terms Based on Reference Current Feed-Forward [#69]*  
Sizhan Zhou, Jinjun Liu and Zhang Yan   
, Xi'an Jiaotong University, China

Injecting negative sequence current into the grid can improve the operating performance of grid-connected voltage source converters under unbalanced grid voltage conditions. In this paper, a dual sequence current control scheme was proposed to quickly track positive- and negative-sequence sinusoidal currents with zero steady state error, implemented in double synchronous reference frames and without requiring current positive- and negative-sequence component decomposition. The proposed method applied a proportional integrator controller in positive synchronous reference frame and only a integrator in negative synchronous reference frame. A reference cross transformation was introduced to avoid extracting current sequence components. Moreover, decoupling terms based on reference current feed-forward were used to realize decoupling control for both positive- and negative-sequence currents. Experimental tests were implemented on a laboratory prototype with 2kHz switching frequency to demonstrate the performance of the proposed dual sequence current control scheme.

**P902***Injecting 3rd Harmonic into the Input Curent to Improve the Power Factor of DCM Buck PFC Converter [#112]*  
Xufeng Zhou, Kai Yao, Hui Li, Fei Yang and Mingcai Kang   
, Nanjing University of Science and Technology, China; Nanjing university of science and technology, China

The conventional Buck PFC converter adopts constant duty cycle control (CDCC), which can improve the PF to some degree. However, the peak and RMS values of the inductor current are large, which also occurs to the switch and diode. This paper derives the expressions of the input current and PF of DCM Buck PFC converter, and based on which, a kind of injecting 3rd current harmonic control (ICHC) is proposed so as to improve the PF in the whole input voltage range. Besides a higher PF, the proposed novel control achieves a lower output voltage ripple, a smaller rms value of the inductor current and a higher efficiency than the conventional control. The experimental results from a 120 W universal input prototype are presented to verify the validity of the proposed method.

**P903***Investigation of Reducing the Influence of Digital Control Delay to LCL-Type Grid-Connected Inverter [#188]*  
Guoshu Zhao, Junyang Ma, Liuliu Huang and Yu Tang   
, Jinling Institute of Technology, China; NUAA, China

Digital control system usually introduces a beat of delay, which includes PWM upload delay and zero-order holder delay. The delay not only reduces the system phase margin, but also changes the impedance characteristics of active damping, which influences the system minimum phase property and threatens the stability of the injected current. In this paper, a PWM real-time upload method and the detailed digital implementation steps are proposed to eliminate PWM upload delay. Then the first-order high pass filter is proposed to compensate the zero-order holder delay of resonance frequency band. The combination of the two schemes increases the system phase margin and improves the compatibility between switch frequency and LCL resonance frequency, which makes system always maintain minimum phase property. A 3KW prototype is designed, and the proposed control method is verified by experiments.

**P904***Repetitive Control for Grid Connected Inverters with LCL Filter under Stationary Frame [#211]*  
Yi Xiao, Gan Wei, Xueguang Zhang, Qiang Gao and Dianguo Xu   
, Harbin Institute of Technology, China

In the synchronous rotating frame, coupling exists in the mathematical model of grid-connected inverter with LCL filter. Severe distortion will occur in the output current of inverter when grid voltage is unbalanced with harmonics contained.One basic measurement for power quality is the total harmonic distortion (THD) of the grid current, it should be no more than 5% for grid- connected photovoltaic array and wind turbines. In this paper a scheme of repetitive control for three-phase grid-connected inverters with LCL filter under stationary frame is proposed. The THD of the injected grid current is reduced effectively with the proposed scheme.Firstly repetitive control theory is briefly introduced.Grid-connected inverter with LCL filter is then modeled and the impact of unbalanced grid voltage and harmonics to grid-connected current is analyzed.In the proposed theory two separate decoupled control systems can be achieved when the mathematical model of grid-connected inverter with LCL filter is under stationary frame, hence complex decoupling process is not required.Then considering the hardware parameter of LCL filter and the influence of the system delay, specific design method of the repetitive controller is provided and tedious debugging process is avoided.Lastly experimental results verify the validity of the theoretical analysis and the feasibility of the proposed control strategy.

**P905***Direct Instantaneous Ripple Power Predictive Control for Active Ripple Decoupling of Single-Phase Inverter [#1103]*  
Baoming Ge, Xiao Li, Haiyu Zhang, Yushan Liu, Bayhan Sertac, Robert S. Balog and Haitham Abu-Rub   
, Texas A and M University, United States; Texas A and M University at Qatar, Qatar

Active ripple decoupling technique of single-phase inverter is a popular topic to minimize the dc-link capacitance. However, the existing control methods are based on tracking sinusoidal or predetermined voltage waveform of compensation capacitor, where they assume the inverter outputs are pure sinusoidal voltage and current. Therefore, the performance of existing methods degrades when the inverter output voltage and current are not pure sinusoidal. Furthermore, the limited dynamic performance threatens the safety of dc-link capacitor when the load changes, because the inrush ripple power is injected into dc link with small capacitance and the dc-link voltage will suddenly rise up when the ripple power is not buffered during transients. In this paper, a direct instantaneous power predictive control is proposed to buffer ripple power of single-phase inverter, which combines instantaneous ripple power control with model predictive control to overcome the issues above. The proposed method tracks instantaneous ripple power rather than voltage or current waveform. In this way, it can fully buffer all ripple powers in the system even for distorted output voltage and current of inverter; the voltage waveform of capacitor has the different shape in different operation cases, which enables the full utilization of storage capacitor. Model predictive control makes the proposed method have fast dynamic and perfectly compensate ripple power during transients and steady states. The buck-type active ripple decoupling circuit is chosen by comparing with another typical topology to implement the proposed method. Simulation and experimental results on a 3-kW prototype verify the theoretical analysis and the proposed control method.

**P906***Input-Output Feedback Linearization Based Control for Quasi-Z-Source Inverter in Photovoltaic Application [#535]*  
Hong Gong, Yuan Li, Yuhong Wang and Rui Zhang   
, Sichuan University, China

The quasi-Z-source inverter (QZSI) has been presented suitable for solar photovoltaic applications mainly because of its one stage buck/boost capability and improved reliability. Carefully designed closed-loop control strategy is usually demanded by QZSI in photovoltaic applications for voltage boost, grid- connection and the maximum power point tracking (MPPT). Cascaded QZSI as to further step up voltage has even put on higher controlling requirements because of the interactive influence of one cascaded module on another. However, commonly used small signal analysis is a local linearization approach which is limited to represent the model of QZSI near its equilibrium point. Moreover, the high order state equation of the quasi-Z-source network usually provides hurdle for high performance controller with stable or fast response. This paper presents an input-output feedback linearization based control strategy for QZSI in two purposes: 1) to build a global linearized QZSI model with a wide operating range; and 2) to help design a controller with improved stable and dynamic performance. An average model for QZSI using state space averaging method is firstly developed. According to the analytic relation of system state variables, i.e. capacitor voltage and inductor current of the QZSI network, the fourth-order mathematical model is reduced to the second-order. Input-output feedback theory is applied to the state space averaging model, where inductor current is selected deliberately as the output of the controller's inner loop. A dc-link feedback loop is developed to validate the input-output feedback linearized model. Evidences are provided by simulation and experiment to show the effectiveness of the proposed controller, where the effect of unstable zero- dynamic on dc-link voltage is reduced, and consequently the transferring of disturbance from dc side to the ac side of the QZSI is mitigated effectively.

**P907***A Novel Neutral Point Potential Control for the Three-Level Neutral-Point-Clamped Converter [#599]*  
Hsin-Chih Chen, Meng-Jiang Tsai, Yao-Bang Wang and Po-Tai Cheng   
, National Tsing Hua University, Taiwan

Three-level neutral-point-clamped (NPC) converters/inverters have become a popular topology for not only medium-voltage ($1$k-$33$k) but also low-voltage level industrial application because of its reduced transistor block voltage and lower output current distortion. The neutral point voltage balancing control is one of the important issues of NPC converter to ensure system operation since the voltage drift in neutral point could lead to low-frequency current distortion and increases the risk of over-voltage in power electronic semiconductor devices. This paper provides a zero-sequence voltage (ZSV) injection to charge and discharge electric potential in the upper or the lower capacitor for unipolar switching. In addition, a novel neutral point potential control by bipolar switching is presented in this paper, which has better control dynamic under pure reactive power operation. The concept of these two neutral point potential control methods will be introduced, and then the laboratory test results are presented for verification.

**P908***Phase Leading Input Current Compensation for CRM Boost PFC Converter [#646]*  
Chengdong Zhao, Junming Zhang and Xinke Wu   
, Zhejiang University, China; Zhejiang university, China

The traditional boost PFC converter in critical conduction mode (CRM) usually suffers from low power factor (PF) in high input voltage and light load conditions due to the influence of the differential mode (DM) capacitor. With the capacitive current flowing into the DM capacitor, the input current has an evident leading phase and a period of dead time in these conditions. In order to solve this problem, this paper proposes a simple improved peak current mode (PCM) control scheme for a CRM boost PFC converter by adding several passive components, which can compensate an equivalent capacitive current to the input current so that the leading phase and dead time of the input current can be eliminated and the PF is greatly improved. The theoretical analysis is presented and the experimental results verify the advantages of the proposed control scheme.

**P909***Paralleled Inverters with Zero Common-mode Voltage [#110]*  
Dong Jiang and Zewei Shen   
, Huazhong University of Science and Technology, China

This paper introduces a PWM method for paralleled inverters which can achieve zero common-mode voltage. The paralleled inverters are connected through coupling inductors to the load. Based on the voltage vectors in each inverter, paralleled voltage vectors are proposed to combine the reference voltage. The action time can be distributed to each inverter and achieve zero common mode voltage for output. The distribution of voltage vectors in the two inverters is balancing the voltage of the two inverters in each switching cycle to make sure the circulating current can be easily controlled through small coupling inductors. Simulation and experimental results are provided to validate the proposed method and showing that it is benefiting for both CM and DM noise reduction.

**P910***A Voltage Clamp Circuit for the Real-Time Measurement of the On-State Voltage of Power Transistors [#119]*  
Lei Ren, Qian Shen and Chunying Gong   
, College of Automation Engineering Nanjing Univer, China

For real-time monitoring of the on-resistance of a power transistor, the voltage and current should be measured during the switching operation. When the voltage waveform is measured, the amplifier inside the measuring oscilloscope may be distorted if the range of the measurement channel is not set wide enough to measure both on-state and off-state voltage levels, resulting in failure to accurately measure the voltage. Conventional circuits partially solve this problem by clamping the off-state voltage to a lower value. However, they introduce problems such as voltage peaks, measurement offset, and delays caused by RC time constants. In this paper, traditional clamping circuits are explained and discussed to illustrate their disadvantages first. Then, a new voltage clamp circuit is presented. The proposed circuit can solve the problems of RC time constants and voltage peaks during state transitions of the device under test. Finally, the performance of the proposed circuit is illustrated by measurements on a 100-kHz Buck converter.

**P911***Error-Voltage Based Open-Switch Fault Diagnosis Strategy for Matrix Converters with Model Predictive Control Method [#323]*  
Hui Deng, Tao Peng, Hanbing Dan, Mei Su and Jingrong Yu   
, Central South University, Jiangxi Kangcheng Co., China

This paper proposes an error-voltage based open-switch fault diagnosis strategy for matrix converter (MC). First, finite control set-model predictive control (FCS-MPC) method is used to operate the MC. Meanwhile, based on the analysis of the operating state under fault condition, the fault model of MC is established. Second, the fault diagnosis strategy is implemented in three steps: to begin with, the occurrence of fault is detected by monitoring the measured load currents. Then, the faulty phase is identified considering the output line-to-line voltage error. After that, by using the switching state of the faulty phase, the faulty switch is located. The fault diagnosis method can accurately and quickly locate the faulty switch without additional voltage sensors. Finally, simulation results are presented to demonstrate the feasibility and effectiveness of the proposed strategy.

**P912***Instrumented Diode Dedicated to Semiconductor Temperature Measurement in Power Electronic Converters [#496]*  
Ibrahima Ka, Yvan Avenas, Laurent Dupont, Mickael Petit, Raha Vafaei, Benoit Thollin and Jean-Christophe Crebier   
, Univ. Grenoble Alpes, G2Elab, F-38000 Grenoble, France; CNRS UMR 8029, SATIE, ENS, 94230 Cachan, France

Temperature measurement of semiconductor components is essential, in particular to evaluate performances and to propose health monitoring of power modules. ThermoSensitive Electrical Parameters (TSEPs) are widely used to estimate a representative temperature of these components, mainly in non-operating conditions, different from the real environment of the latter (offline measurements). Nevertheless, some TSEPs may be adapted to online temperature measurements, in operating conditions of power converters. It is however difficult to evaluate the accuracy of those TSEPs. This paper presents an instrumented chip dedicated to estimate the temperature in power electronic modules under functional constraints. Thus, it offers a reliable and robust tool for temperature measurements in power electronic converters. Preliminary results presented in this paper concern the technological process of realization and demonstrate the good functioning of this instrumented chip under power dissipation and switching conditions.

**P913***Reliability Odometer of Power Semiconductor Device Used for high performance high power amplifiers [#1240]*  
Fei Xu, Juan Antonio Sabate, Xi Lu, Ruxi Wang, Louis Martin Frigo, Margaret Ann Wiza, Syedsaad Asif Ali and Melissa Jean Freeman   
, GE Global Research, China; GE Global Research, United States; GE Healthcare Systems, United States

This paper presents a real-time evaluation of power semiconductor devices in a high performance high power amplifier. The proposed method can represent the life status of the semiconductor modules in odometer format. A special challenging case are pulsating load applications like an MRI gradient driver system. The general concepts presented have been evaluated in detail for the MRI case. A detailed Cauer thermal network is proposed to estimate the temperature from junction to ambient with the combination of non-ideal heatsink. Rainflow counting method and Palmgren-Miner linear damage accumulation rule are introduced and designed for the on-line cycle counting and real-time lifetime consumption estimation. The paper explains the design of the method considerations to minimize the computing time and memory requirements different from standard off line or post analysis approaches. Simulation models and hardware prototype are built to validate the design and analysis.

**P914***Energy and Computational Efficient Estimation of Battery Intrinsic Parameters [#1366]*  
Chun Sing Cheng, Ricky Wing Hong Lau, Henry Shu Hung Chung and N.K. Rathi   
, City University of Hong Kong, Hong Kong; Premier Technologies Ltd, Hong Kong

This paper presents an efficient battery parameter extraction technique with energy recycling feature. Based on transferring the testing energy to and from a supercapacitor (storage device) through a bidirectional DC-DC converter, the charging and discharging current profile of a battery can be obtained for analyzing the battery characteristics and parameters extraction. With the testing energy stored in a supercapacitor, the concern of thermal management is eliminated. By applying a newly modified efficient particle swarm optimization algorithm, the voltage and current data are used to estimate the intrinsic parameters of a high-order electrical battery model. A prototype has been implemented for extracting the intrinsic parameters of four different types of 12V lead-acid battery, and with evaluation current evaluated up to 150A. The estimated parameters have been verified against the theoretical predictions as well as the test results obtained from the NHR battery testing system.

**P915***Snubber Capacitors Optimization for Super-Junction MOSFET in the ZVS Full-Bridge Inverter [#530]*  
Yenan Chen, Guangyuan Liu, Changsheng Hu and Dehong Xu   
, Zhejiang University, China

A zero voltage switching full-bridge inverter and its modulation schemes have been investigated in previous literatures. Parallel snubber capacitors are utilized to reduce the turn off loss of super unction MOSFETs in the ZVS full bridge inverter. However due to the MOSFET's nonlinear output capacitance the ZVS commutation is unable to be realized and high voltage spike occurs on switching devices under light load condition. The problem is solved by changing the position of the snubber capacitors.

Poster Session: Electrical Machines

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Bruno Lequesne, Mohammad Islam

**P1101***A Computational Technique for Iron Losses in Electrical Machines [#450]*  
Omar Bottesi, Luigi Alberti, Ruth V. Sabariego and Johan Gyselinck   
, Free University of Bozen-Bolzano, Italy; Katholieke Universiteit Leuven (KU Leuven), Belgium; Universite Libre de Bruxelles (ULB), Belgium

This paper aims to compare different methods for the computation of the iron losses. First of all, a brief recall on iron losses models is considered. In particular, Bertotti's formula, a homogenization technique and a vectorized Jiles-Atherton model are implemented. Afterwards, the adopted methods are validated considering an iron ring and an inset PM synchronous machine. A comparison between experimental measurements on the iron ring and the adopted methods is presented. The inset PM synchronous machine is simulated in different operating conditions: both at standstill and no load. Good agreement has been found between the results.

**P1102***Saliency Harmonic Induction Motor Speed Estimation Using Artificial Neural Networks [#34]*  
Abdulelah Alkhoraif and Donald Zinger   
, Northern Illinois University, United States

Several methods have been proposed to measure the speed of an induction machine without the need for external speed transducers. These sensorless methods typically use observers, require injected signals, or are dependent on the detecting a specific harmonic. This paper investigates using neural networks to identify the speed of a machine using a range of harmonics without specific knowledge of machine parameters. As a proof of concept currents measured from various machines are analyzed with the proposed method. This analysis showed that such a system has the potential for relatively accurate speed determination.

**P1103***Reclosing Transients in Standard and Premium Efficiency Induction Machines in the Presence of Voltage Unbalance [#241]*  
Tumelo Gabaraane, Paul Barendse and Azeem Khan   
, Masters Student, South Africa; Supervisor, South Africa; Co-supervisor, South Africa

The impact of restarting an induction machine, while coasting, is investigated in this paper. When restarting a motor, high peaking currents and torque transients appear. As a result, possible damage to the rotor shaft could occur together with destabilising the power system which could lead to a fluctuating supply voltage levels. This paper investigates the restarting of two different efficiency class induction machines and analyses how a shift in phase between the supply and residual voltage affects the restarting transients. Previous studies have been carried out on standard efficiency induction machines (SEIM), however this paper aims to compare the impact of restarting on the standard and premium efficiency induction machines (PPEIM). A further contribution is made by studying the impact of restarting these machines in the presence of voltage unbalance.

**P1104***Parameter sensitivity of large electric machines [#22]*  
Jemimah Akiror, Pragasen Pillay and Arezki Merkhouf   
, Concordia University, Canada; Hydro Quebec, Canada

Machine simulation models allow the use of embedded numerical computation techniques. The numerical model and computational accuracy is usually gauged by comparison with experimental measurements. In this paper a large hydro generator is modeled and the sensitivity of various model parameters is investigated by comparing the simulated results with experimental measurements from four units of the same design. The machine open circuit voltage was found to be very sensitive to the airgap and stator B-H curve. Moreover, for 2D simulations the effective length is also important because it should account for differences in the stator and rotor lengths, in addition to the presence of radial air ducts. A 20% variation in operation airgap between two machines of the same design induced over 18% difference in open circuit voltage. Reduction in permeability of the soft magnetic materials resulted in agreement between the numerical and measured results at saturation. Consequently for large machines, the B-H curves from the Epstein measurements are insufficient and should be adjusted accordingly.

**P1105***Optimal Winding Arrangement of a Surface-Mounted Permanent Magnet Motor for Torque Ripple Reduction [#84]*  
Junichi Asama, Yamamoto Yo, Oiwa Takaaki and Chiba Akira   
, Shizuoka University, Japan; Tokyo Institute of Technology, Japan

We are aiming to develop a high precision micro-milling machine with a high speed spindle which is driven by a permanent magnet motor and supported by active magnetic bearings. The torque ripple, however, may have influence on the positioning accuracy. As a first step of this study, we investigate torque ripple reduction of a permanent magnet motor. This paper considers optimal winding arrangement of a 2-pole/12-slot surface permanent magnet motor with double-layer distributed winding to minimize magnet torque ripple. The magnet torque with double-layer winding is theoretically derived by considering the spatial harmonics of the MMF distribution. The torque ripple with 6wt variation is theoretically zero when the ratio of the secondary winding with respect to the primary one is about 0.37. In addition, the PM step skew is investigated to reduce the cogging torque, based on three-dimensional finite element method analysis. The experimental results demonstrate that the optimal double-layer winding configuration with the winding ratio of 0.37 is effective to reduce the magnet torque ripple.

**P1106***Numerical Study of Convective Heat Transfer in the End Region of A Totally Enclosed Permanent Magnet Synchronous Machine [#126]*  
Ayoub Ben Nachouane, Abdenour Abdelli, Guy Friedrich and Stephane Vivier   
, IFP Energies nouvelles, France; Sorbonne Universites UTC, France

This paper proposes a numerical approach for the determination of convective heat transfer coefficients in the end region of a totally enclosed permanent magnet synchronous machine used as an integrated starter generator in a hybrid vehicle. A simplified numerical model based on CFD methods is developed to understand the mechanism of convective heat transfer over a large operation range. The effect of the rotation speed on the variation of the convective heat transfer coefficients inside the end region is thoroughly investigated. Heat flux paths are also identified for the entire operating range.

**P1107***Torque Improvement of Wound Field Synchronous Motor for Electric Vehicle by PM-assist [#279]*  
Sung-Woo Hwang, Jae-Han Sim, Jung-Pyo Hong, Jiyoung Lee and Jongmoo Kim   
, Hanyang University, Korea, Republic of; Korea Electrotechnology Research Institute, Korea, Republic of

In order to improve the performance of the wound field synchronous motor (WFSM), the permanent magnet assist (PM-assist) is investigated in this paper. The effect of the permanent magnet assist is dependent on the inserted position of the permanent magnets. Thus, four models whose permanent magnets are inserted at each different positions are suggested. Then, the most effective position of the permanent magnet is decided by the mean torque per employed amount of the permanent magnet. By inserting the permanent magnets into the decided position of a WFSM designed for a small electric vehicle traction, the PM-assisted WFSM is designed. By comparing the torque and the efficiency of the original WFSM and the PMassisted WFSM, the effectiveness of the PM-assist is figured out. Finally, the validity of this research is verified by the experiment using the manufactured WFSM.

**P1108***Torque Ripple Reduction of a Variable Flux Motor [#32]*  
Amirmasoud Takbash, Maged Ibrahim and Pragasen Pillay   
, Concordia University, Canada; Pharos University, Egypt

This paper examines torque ripple in a new topology of variable flux machine with AlNiCo magnet. To reduce the torque ripple, the design and finite element modeling of this machine are reviewed and the finite element model results are verified with the prototyped motor. The effects of various electrical, magnetic and geometrical parameters such as load, magnetization level of the magnet, tooth and yoke width and magnet dimensions, on both torque mean value and torque ripple are discussed using the verified finite element model. Finally, modified rotor structure is presented that reduces the torque ripple by 35% with the same torque mean value and magnetization current for the motor. The torque ripple of the modified design is analyzed for a wide range of load and speed.

**P1109***An Analytical Model for a Spoke Type Variable Flux Permanent Magnet Motor on No-load Condition [#33]*  
Amirmasoud Takbash and Pragasen Pillay   
, Concordia University, Canada

This paper presents an analytical model, for a new spoke type variable flux machine, with AlNiCo magnets, in the no-load condition. This method is based on the solution of a simple magnetic equivalent circuit of spoke type machines. The effect of stator slots on the air gap magnetic flux density is studied and uneven air gap length is modeled. Based on the no-load air gap magnetic flux density, the mean value of torque is calculated. The analytical and finite element design procedure of spoke type variable flux motor are reviewed briefly. Both analytical and finite element models are verified using test results of the prototyped motor and the effect of magnet length on the torque mean value is discussed, as well.

**P1110***Sensitivity of Manufacturing Tolerances on Cogging Torque in Interior Permanent Magnet Machines with Different Slot/Pole Number [#63]*  
Xiao Ge and Z. Q. Zhu   
, University of Sheffield, United Kingdom

The cogging torque is usually very sensitive to the manufacturing tolerances during machine mass production, and this paper investigates the different sensitivities between interior permanent magnet (IPM) machines with different slot/pole number combinations. Exemplified by two typical combinations, i.e. 12-slot/8 sl slot/8 sl slot/8 slot/8-pole and 12-slot/10-pole designs, the fundamental performance is firstly analyzed under ideal conditions. Then, with the tolerances of PM diversity and tooth-bulges considered, the most sensitive cases are identified for the two machines respectively, based on which the ultimate values of additional cogging torques are obtained and compared. In order to verify the different sensitivities, the field spatial harmonics in the two machines with and without considering the tolerances are further analyzed, from which the different origins of additional cogging torque components can be obtained respectively. Finally, the IPM prototypes with and without amplified tolerances are fabricated and tested to verify the analyses.

**P1111***Cogging Torque Minimization in Flux-Switching Permanent Magnet Machines by Tooth Chamfering [#278]*  
Xiaofeng Zhu, Wei Hua and Ming Cheng   
, Southeast University, China

Due to the nature of doubly salient structure and high air-gap flux density, flux-switching permanent magnet (FSPM) machines typically suffer from large cogging torque, causing undesired acoustic noise and vibration, especially at low speeds. In this paper, various tooth chamfering methods for a 12/10 FSPM machine are proposed to reduce cogging torque. The influences of both circular bead and right angle as well as their possible combinations on cogging torque are investigated by 2D finite element analysis (FEA), and it turns out that employing right angles in both stator and rotor teeth is the most effective solution. Further, in order to explain this phenomena, the air-gap flux density is analyzed. Besides, the impacts on phase back electro-motive-force and electromagnetic torque are also evaluated. The predicted results indicate that the proposed technique can significantly reduce the peak value of cogging torque from 2.6Nm to 0.4Nm, while the reduction of average torque is only about 1.6%, which turns out to be an improvement when compared with the approach employed in previous literatures.

**P1112***Experimental research on the oil cooling of the end winding of the motor [#304]*  
Ye Li, Tao Fan, Wei Sun, XuHui Wen and Qi Li   
, Institute of Electrical Engineering of Chinese A, China

for gaining an effective cooling performance for motor, water cooling is commonly utilized. But as the requirement for power density increasing, solely the water cooling is not sufficient. This is duo to the thermal resistance of the end winding to the water is large. To obtain lower temperature of the end winding, a new cooling method is studied. The stator and the rotor are separated by an ultrathin sleeve made of glass fiber, and the end winding is directly cooled by the oil in the space formed by the sleeve. Four different cooling schemes are evaluated through experiments. It is proved that the temperature of the end winding is reduced significantly, and the overall heat dissipation of the stator is improved.

**P1113***A Computationally Efficient Method for Calculation of Strand Eddy Current Losses in Electric Machines [#1293]*  
Alireza Fatemi, Dan Ionel, Nabeel Demerdash, David Staton, Rafal Wrobel and Chong Yew Chuan   
, Marquette University, United States; University of Kentucky, United States; Motor Design Limited, United Kingdom; University of Bristol, United Kingdom

In this paper, a fast finite element (FE)-based method for the calculation of eddy current losses in the stator windings of randomly wound electric machines with a focus on fractional slot concentrated winding (FSCW) permanent magnet (PM) machines will be presented. The method is particularly suitable for implementation in large-scale design optimization algorithms where a qualitative characterization of such losses at higher speeds is most beneficial for identification of the design solutions which exhibit the lowest overall losses including the ac losses in the stator windings. Unlike the common practice of assuming a constant slot fill factor, sf , for all the design variations, the maximum sf in the developed method is determined based on the individual slot structure/dimensions and strand wire specifications. Furthermore, in lieu of detailed modeling of the conductor strands in the initial FE model, which significantly adds to the complexity of the problem, an alternative rectangular coil modeling subject to a subsequent flux mapping technique for determination of the impinging flux on each individual strand is pursued. The research focus of the paper is placed on development of a computationally efficient technique for the ac winding loss derivation applicable in design-optimization, where both the electromagnetic and thermal machine behavior are accounted for. The analysis is supplemented with an investigation on the influence of the electrical loading on ac winging loss effects for a particular machine design, a subject which has received less attention in the literature. Experimental ac loss measurements on a 12-slot 10-pole stator assembly will be discussed to verify the existing trends in the simulation results

**P1114***Core Loss Estimation in Electric Machines with Flux Controlled Core Loss Tester [#1516]*  
Burak Tekgun, Yilmaz Sozer, Igor Tsukerman, Parag Upadhyay and Steven Englebertson   
, University of Akron, United States; ABB, United States

The complexity of core loss estimation is an essential limitation for electric machine design engineers. It is critical to estimate the core losses and reduce them in the design stage to improve the machine efficiency. Current estimation methods based on the Steinmetz equation and loss separation are not accurate enough even at the rated conditions. This work describes a loss estimation technique combining finite element analysis (FEA) and actual core loss measurements. First, flux waveforms from various parts of the electric machine are determined using finite element analysis (FEA), then identical flux density waveforms are generated in a toroidal wound core made out of the same material as is used in the machine. The loss is measured per unit mass, and then the total motor core loss is calculated by combining the measured W/kg loss values for predefined sections of the motor. Estimation results are provided and compared with the Bertotti iron loss and loss surface methods. The proposed method is shown to improve the accuracy of loss estimation.

**P1115***Thermal Analysis of a Three-Phase 24/16 Switched Reluctance Machine Used in HEVs [#1588]*  
Michael Kasprzak, James W. Jiang, Berker Bilgin and Ali Emadi   
, McMaster Automotive Resource Centre (MARC), Canada

This paper presents the thermal analysis of a 60 kW switched reluctance motor (SRM) under peak operating conditions for traction application in a hybrid electric vehicle (HEV). The SRM has 24 stator poles and 16 rotor poles, and three-phases. Heat generation losses are determined using finite element analysis (FEA) electromagnetic simulations and these losses are input into a lumped parameter thermal network (LPTN) simulation representing the thermal circuit of the electric machine. A range of coolant inlet temperatures are input and the testing of various priority operating speed points leads to the analysis of the rise in temperature of different components within the machine. By applying temperature limiting constraints of the copper windings and the rotor lamination surface, the operating times with varying coolant inlet temperatures and operating speeds can be determined.

**P1116***Pre-Drive Test of an Implemented Novel Radial-Gap Helical ROTLIN Machine [#307]*  
Christophe Cyusa Simba and Yasutaka Fujimoto   
, Yokohama National University, Japan

The future trend of mechanical systems is to substitute most of them by Permanent Magnet (PM) and/or Electromagnetic based ones. This paper presents an extension research on Design, Modeling, Simulation and Implementation Based Control of a novel ROTLIN (Rotary-Linear) Radial Gap Helical Machine. This is an hybrid of Magnetic Screw with a Synchronous Motor by modifying the design concept. The implemented machine is comprised of Stator, Mid-Layer Rotor and Inner Layer Translator, and tested as a high thrust force actuator. In the pre- drive tests, the back-EMF was measured and a relative rotational speed derived; Encoder signals and Position tracking were confirmed as well. The PD controller combined with DOB was designed but could not alleviate all vibrations in position response. The Pre-Drive Tests were conducted and Open Loop V/f control was used for preliminary experiments, consequently the Rotary and and relative Linear motions were confirmed.

**P1117***Hybrid Excitation Topologies of Synchronous Generator for Direct Drive Wind Turbine [#488]*  
Maxime Ployard, Ammar Aymen, Gillon Frederic, VIdo Lionel and Laloy Daniel   
, Ecole Centrale de Lille, France; JEUMONT Electric, France; Universite de Cergy Pontoise, France; EC Lille, France

An analysis of Hybrid Excitation Synchronous Generator (HESG) topologies for a direct drive wind turbine is investigated. Through an optimization process, the topologies of HESG are compared regarding the cost and the total losses. The optimizations are performed at the nominal on-load operating point of the generator. The trade-offs between each topology are analyzed according to a set of Pareto fronts. An instrumented prototype of 900kVA approves the design process. Finally, the best Pareto optimal solutions are compared during an experimental operating cycle of the direct drive wind turbine. The efficiency improvement emphasizes the interest of the design by optimization.

**P1118***Resonant Based Backstepping Direct Power Control Strategy for DFIG Under Both Balanced and Unbalanced Grid Conditions [#58]*  
Xiaohe Wang, Dan Sun and Ziqiang Zhu   
, Zhejiang University, China; University of Sheffield, England

This paper proposes a resonant based backstepping direct power control (BS-DPC) strategy for doubly fed induction generator (DFIG) under both balanced and unbalanced grid conditions. Proper formulae for the BS-DPC strategy are obtained based on the elaborated analysis of the mathematical model of DFIG. The influence of the unbalanced grid voltage on the normal BS-DPC is analyzed. Furthermore, a resonant based improved strategy is proposed to achieve different control targets under unbalanced grid condition without the need of decomposition of positive and negative sequence components. Comparative experimental studies of the resonant based BS-DPC and the normal BS-DPC for DFIG are conducted to validate the effectiveness of the proposed strategy under both balanced and unbalanced grid conditions. In addition, the experimental results also prove that the proposed resonant based BS-DPC can achieve a satisfying transient performance.

**P1119***Design and Analysis of a New Five-Phase Brushless Hybrid-Excitation Fault-Tolerant Motor for Electric Vehicles [#107]*  
Li Zhang, Ying Fan, Ronghua Cui, ChenXue Li and Ming Cheng   
, Southeast University, China

High reliability and wide range of speed regulation are key factors for motor driving system in electric vehicles (EVs). To meet the requirement for EV application, this paper proposes and investigates a new five-phase brushless fault-tolerant hybrid-excitation (FTHE) motor. First, the single concentrated stator winding is adopted to achieve fault-tolerance. The unequal teeth width and the asymmetric air-gap length are designed to optimize electromagnetic performances, such as back-EMF and torque. In addition, to realize flux- regulation, simple structure and no sliding contacts, based on the utilization of the high-harmonic component of the stator MMF, the rotor field winding and the rotor harmonic winding are designed. Moreover, topology and operation principle of the proposed motor are analyzed. Also, the characteristics of the proposed motor are investigated by using finite-element analysis. Finally, the experimental results are given to verify the validity of the proposed motor.

**P1120***Multi-objective Design Optimisation and Pareto Front Visualisation of Radial-flux Eddy Current Coupler for Wind Generator Drive Train. [#244]*  
Abram Stephanus Erasmus and Maarten Kamper   
, Stellenbosch University, South Africa

In this paper the design optimisation of a 2.2 kW, double rotor, radial axis eddy current coupling operating at 97 \% efficiency, designed for a wind turbine drive train application is described. A computationally efficient finite element analysis in conjunction with gradient (MMFD) and population (NSGA) based design optimisation algorithms is used in order to obtain an optimal coupling design. The two optimisation algorithms are evaluated in terms of speed and accuracy. The comparison between copper and aluminium conductor materials revealed that the aluminium is the preferred material in terms of mass and cost. A gradient-based analysis method with regard to the input parameters of the genetic optimisation algorithm's pareto curve is proposed.

**P1121***Reducing Estimated Parameters of a Synchronous Generator for Microgrid Applications [#706]*  
Mohammad Rasouli and Reza Sabzehgar   
, Penn State Behrend, United States; San Diego State University, United States

Synchronous generators are widely utilized in microgrids with high penetration of distributed renewable energy resources for small scale power generation. An accurate model of a synchronous generator is key to effective planning and operation of a grid-tied microgrid as well as stabilizing the frequency and regulating the voltage in an islanded microgrid. In this paper, a new strategy, based on the sensitivity trajectory analysis, for modeling a synchronous generator, which influences the transients of a microgrid greatly, is proposed. This method partitions the model parameters into significant and less significant sets. It is shown that in microgrid modeling, only the significant parameters need to be identified, and the remaining parameters can be replaced by typical values as they do not influence the model outputs critically. Reduction of the estimated parameters allows for modeling other components using on-line measurements, increases the reliability of the identified parameters and generalization capability of the characterizing model. The performance of the proposed approach is demonstrated by modeling a 5.3 MVA synchronous generator utilized in the San Diego State University microgrid.

**P1122***Brushless Dual-Electrical-Port, Dual Mechanical Port Machines Based on the Flux Modulation Principle [#815]*  
Dawei Li, Ronghai Qu, Jian Li, Dong Jiang, Xiang Ren and Yuting Gao   
, Huazhong University of Science and Technology, China

Based on the flux modulation principle, this paper proposes a novel brushless dual-electrical port dual mechanical port (DEDM) machine. From the view of derived torque equations, the proposed topology can be regarded as a combination of a motor/generator with a brushless magnetic continuously variable transmission. First, the structure and operation principle of the proposed machine are introduced. Then, the function and operation modes are discussed. Moreover, some parasitic effects which may influence the machine performance are also researched. Finally, several key performances are investigated and analyzed by finite element algorithm (FEA).

Poster Session: Electric Drives

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Uday Deshpande, Gianmario Pellegrino

**P1301***An Equivalent Dual Three-phase SVPWM Realization of the Modified 24-Sector SVPWM Strategy for Asymmetrical Dual Stator Induction Machine [#60]*  
Kun Wang, Xiaojie You, Chenchen Wang and Minglei Zhou   
, Beijing Jiaotong University, China

A modified space vector pulse width modulation (SVPWM) strategy based on vector space decomposition and its equivalent dual three-phase SVPWM realization are proposed in this paper, which is suitable for two-level six-phase voltage inverter fed asymmetrical dual stator induction machines (DSIMs). The DSIM is composed of two sets of symmetrical three-phase stator windings spatially shifted by 30 electrical degrees. The proposed SVPWM technique can reduce the torque ripple and suppress the harmonic currents flowing in stator windings. Above all, the equivalent relationship between the proposed SVPWM technique and the dual three- phase SVPWM technique has been demonstrated, which allows easy implementation for digital signal processor (DSP). Simulation and experimental results, carried out separately on a simulation system and a 3.0 kW DSIM prototype test bench, are presented and discussed.

**P1302***A Speed estimation method for free-running induction motor with high inertia load in the low speed range [#271]*  
Toshie Kikuchi, Yasushi Matsumoto and Akira Chiba   
, Fuji Electric, Japan; Tokyo Institute of Technology, Japan

Rotational speed sensorless drives need to estimate a rotor speed before an inverter starts when an induction motor is running freely with high inertia load. In this paper new estimation method for the initial rotor speed estimation in particularly low rotational speed has been proposed. To avoid over current and re-generating torque, the double derivation of the secondary flux is utilized. The effectiveness of the proposed method is confirmed experimentally.

**P1303***Design Optimization and Performance Investigation of Novel Linear Switched Flux PM Machines [#20]*  
Qinfen Lu, Yihua Yao, Jiameng Shi, Xiaoyan Huang, Youtong Fang, Yunyue Ye and Wei Xu   
, Zhejiang University, China; Huazhong University of Science and Technology, China

A novel partitioned primary linear switched flux permanent-magnet machine (LSFPMM) is presented. Its primary is divided into two separate parts: one is the armature containing iron core and windings, and the other is magnetic poles containing PMs and iron core. For the optimal design objective of maximum thrust force and minimum thrust ripple, the novel partitioned primary LSFPMM with 9 primary/10 secondary poles is optimized. The electromagnetic performance of this optimized partitioned primary LSFPMM has been analyzed and compared with that of original one. The corresponding prototype of optimal design is manufactured and possible machining errors are discussed. Finally, the measurement is carried out, which verifies the predicted results. The research shows this novel structure has high force performance and is suitable to machine tools, conveyers and punching machine.

**P1304***A Coordinated SVPWM without sector identification for Dual inverter fed Open Winding IPMSM System [#181]*  
Min Chen and Dan Sun   
, Zhejiang University, China

A coordinated space vector modulation (SVPWM) algorithm without sector identifications is proposed for the dual inverter fed open winding interior permanent magnet synchronous motor (IPMSM) system, where the duty ratios of the three phases for each inverter are directly calculated, and no trigonometric function calculations or sector identifications are involved. Moreover, the switching frequency for the whole system will be decreased to 1/3 of that of the conventional modulation scheme which employs one SVPWM for each inverter respectively. A new criterion is defined to evaluate the output voltage ripples, and a comparative investigation on the proposed coordinated SVPWM and other two existing modulation algorithms is exhibited. Experimental results verify the effectiveness and superiority of the proposed strategy.

**P1305***Finite-Control-Set Model Predictive Current Control for PMSM Using Grey Prediction [#302]*  
Wencong Tu, Guangzhao Luo, Rong Zhang, Zhe Chen and Ralph Kennel   
, Northwestern Polytechnical University (NPU), China; Technical University of Munich (TUM), Germany

This paper proposes a finite control set model predictive current control (FCS- MPCC) with grey prediction for surface mounted PMSM drives. The basic FCS-MPCC is combined with grey prediction to improve the dynamic performance current control. Grey system takes into account both certain and uncertain information in real system, and use the rolling optimal grey sequence to predict the control current for cost function. The performance is demonstrated in both simulation and experiment. The results illustrate that FCS-MPCC with grey prediction expresses a good current response under the load disturbance and good performance under different parameter variations. Meanwhile the steady-state performance of current can be assured.

Poster Session: Power Semiconductor Devices, Passive Components, Packaging, Integration, and Materials

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Giovanna Oriti, Enrico Santi

**P1501***The Impact of Triangular Defects on Electrical Characteristics and Switching Performance of 4H-SiC PiN Diodes [#903]*  
Yeganeh Bonyadi, Peter Gammon, Roozbeh Bonyadi, Olayiwola Alatise, Ji Hu, Steven Hindmarsh and Philip Mawby   
, University of Warwick, United Kingdom

In this work the impact of a surface morphological defect, i.e. the triangular defect on fabricated 4H-SiC PiN diodes is explored. Diodes are intentionally fabricated on triangular defects on wafers with 35 (PiN1), and 30 (PiN2) um 4H- SiC epitaxial layers in order to understand their impact on the resulting electrical characteristics and switching performance. We show for the first time the impact of triangular defects on switching characteristics of 3.3kV SiC PiN diodes fabricated on and off-defects and prove that the existence of triangular defects limit the active area of the devices and creates a short through the drift region, which increases the leakage current by almost 6 orders of magnitude higher than the devices off-defect. TEM images obtained from the defects verified these electrical results. Also, the reverse characteristics show that both substrates suffer from soft breakdown. The switching results show that the presence of triangular defects does not negatively affect the carrier lifetime of devices on-defect. In contrary, there is some evidence (especially in lower current values) that the amount of stored charge is increased. However, this depends on the ratio of defect to the active area of the devices.

**P1502***Performance Evaluation of Series Connected 15 kV SiC IGBT Devices for MV Power Conversion Systems [#1163]*  
Kasunaidu Vechalapu, Abhay Negi and Subhashish Bhattacharya   
, North Carolina State University, United States

The 15kV SiC IGBT (2 um and 5 um buffer layer) with chip area of 8.4 x 8.4 mm2 is the state of the art high voltage device designed by Cree Inc. This device is expected to increase the power density of converters and the demonstration of the device in applications like Solid State Transformers has been published. Therefore, it is interesting to investigate the performance of the device in very high voltage (HV) application, where series connection of devices is required. This paper addresses design considerations of series connection of 15kV SiC IGBT devices for high voltage converter applications. A simple RC snubber has been used to control both dvdt and dynamic voltage balancing during turn-off.

**P1503***Comparative Performance Evaluation of Series Connected 15 kV SiC IGBT Devices and 15 kV SiC MOSFET Devices for MV Power Conversion Systems [#1494]*  
Kasunaidu Vechalapu, Abhay Negi and Subhashish Bhattacharya   
, North Carolina State University, United States

The 10-15kV SiC MOSFET and 15kV SiC IGBT (2 um and 5 um buffer layer) are the state of the art high voltage devices designed by Cree Inc. These devices are expected to increase the power density of converters and the demonstration of these devices in applications like Solid State Transformers (SST) have been reported up to 4.16 kV-13.2 kV grid connection. It is interesting to investigate the performance of the devices in very high voltage (greater than 13.2 kV) application, where series connection of devices is required. Therefore, this paper addresses design considerations of series connection of 15 kV Silicon carbide (SiC) IGBT devices and series connection of 10 kV-15 kV Silicon carbide (SiC) MOSFET devices in two separate independent cases and their experimental comparison.

**P1504***Equivalent Circuit Models and Model Validation of SiC MOSFET Oscillation Phenomenon [#1566]*  
Tianjiao Liu, Runtao Ning, Thomas Wong and Z. John Shen   
, Illinois Institute of Technology, United States

SiC MOSFETs are known to provide a better performance compared to Si IGBTs. However, they can also introduce undesirable behaviors like switching oscillations due to the existence of parasitic elements. In this paper, we introduce the turn-on and turn-off switching equivalent circuit models and validate these models with commercially available SiC MOSFETs. Based on the models, theoretical analysis is carried out and the guidance of damping circuit design is provided. Circuit simulations and experimental measurements are performed to validate the modeling method as a general treatment for ultrafast switching applications. In addition, a method of extracting parasitic inductances of packaged SiC MOSFETs using a network analyzer is introduced. The measured parasitic inductance values prove to be more realistic than the values estimated by the device manufacturer when being used in the equivalent circuit models. Furthermore, a detailed justification and experimental validation on the assumption of gate loop resistive contribution are provided.

**P1505***Enabling DC Microgrids with MV DAB Converter based on 15 kV SiC IGBT and 15 kV SiC MOSFET [#1657]*  
Awneesh Tripathi, Krishna Mainali, Sachin Madhusoodhanan, Kasunaidu Vechalapu, Ritwik Chattopadhyay and Subhashish Bhattacharya   
, North Carolina State University, United States

The 15kV SiC IGBT and 15kV SiC MOSFET have been recently developed to enable non-cascaded high-frequency (HF) MV converters. Such direct MV DC interfacing Dual Active Bridge (DAB) converter is getting popular for DC micro-grid application due to higher efficiency, higher power-density and higher MTBF over the cascaded DAB topology. The high dv/dt in these devices on hard-switching with their inherent parasitics, causes increased EMI and switching loss. The suitability of the two family of SiC devices for an application, depends on the switching frequency, load range and magnitude of power, operating temperature and converter power density. This paper compares the two devices for a MV DAB application for dc micro-grid based on simulation and also with supporting MV side converter experiments up to 10kV DC bus and under 5- 20kHz switching frequencies.

Poster Session: Emerging Technologies and Applications

Monday, September 19, 5:30PM-7:00PM, Room: Exhibit Hall, Chair: Xiaonan Lu, Pericle Zanchetta

**P1701***An LC Compensated Electric Field Repeater for Long Distance Capacitive Power Transfer [#73]*  
Hua Zhang, Fei Lu, Heath Hofmann, Weiguo Liu and Chris Mi   
, Northwestern Polytechnical University, China; University of Michigan, United States; San Diego State University, United States

This paper proposes an LC-compensated electric field repeater to extend the transfer distance of a capacitive power transfer (CPT) system. The repeater contains two metal plates, connected with an external capacitor and an external inductor. The plates are used to generate electric fields to transfer power. The external inductor and capacitor are used to resonate with the plates to increase the voltage levels. The repeater is placed between a transmitter and a receiver, which also contains metal plates compensated by an LC network. The repeater can increase the transfer distance of the CPT system without significantly influencing the system power and efficiency. In this paper, the capacitive coupler structure and dimensions are designed and simulated using Maxwell software. Considering all the capacitive coupling between plates, an equivalent circuit model is derived. The fundamental harmonics approximation method is used to analyze the working principle of the circuit. A 150W input power CPT system is designed as an example to validate the proposed repeater structure and compensation circuit topology. The system can achieve an efficiency of 66.9% from dc source to dc load, when the transfer distance is 360 mm and the repeater is placed between the transmitter and receiver.

**P1702***A Selection Method of Mutual Inductance Identification Models Based on Sensitivity Analysis for Wireless Electric Vehicle Charging [#158]*  
Fang Liu, Zhengming Zhao, Yiming Zhang, Kainan Chen, Fanbo He and Liqiang Yuan   
, Tsinghua University, China

Wireless power transfer has been recognized as a promising technology for electric vehicles charging. However, the parking misalignments between the transmitter coil on the ground and the receiver coil inside the car may cause variations in the mutual inductance for the charging system, which will reduce its transfer power and efficiency. In order to improve the transfer efficiency and optimize the operating condition, it is essential to identify the mutual inductance. In this paper, identification models are studied with and without communication feedback from the receiver coil under two typical cases (resonant transmitter and inductive transmitter). A selection method based on sensitivity analysis is proposed to select models of high accuracy against measurement errors and sampling propagations. Simulation and experimental results verify the effectiveness and validity of the proposed method. This work is helpful for evaluating and improving the wireless charging system tolerance against misalignments as well as optimizing its operation condition.

**P1703***Short-Circuit Protection of Power Converters Using SiC Current Limiters [#207]*  
Mahmood Alwash, Mark Sweet, Ekkanath Madathil Sankara Narayanan and Graham Bruce   
, University of Sheffield, United Kingdom; Rolls-Royce plc, United Kingdom

In this paper, a method to limit fault current from DC side short-circuit condition in AC-DC power converters is presented. This approach is based on using Normally-ON SiC-JFETs in series with the DC capacitors as Current Limiting Diodes (CLDs). In this configuration, the gate and source contacts of the JFETs are connected together to make two-terminal devices (VGS=0). Under a fault condition, the capacitors voltage appears across the devices causing them to operate in the saturation region where their current is limited by channel pinch-off and self-heating. Whereas under normal conditions, the CLDs operate in the linear I(V) region where they exhibit low on-state resistances and therefore, have minimal effect upon the converter operation. This paper also includes experimental results to verify the effectiveness of the proposed method in limiting capacitors discharge current during a fault and to demonstrate its small influence on normal operation.

**P1704***Impedance Measurement of Three-Phase Grid-Connected Systems in DQ-Domain: Applying MIMO-Identification Techniques [#417]*  
Tomi Roinila, Tuomas Messo and Aapo Aapro   
, Tampere University of Technology, Finland

Grid impedance and the output impedance of grid-connected inverter are important parameters for analyzing the operation and stability of renewable energy systems. The impedance mismatch between the grid and the inverter may easily destabilize the interface and cause harmonic resonance. Online impedance measurement techniques are required since the impedances vary over time with many parameters. Online impedance measurement enables adaptive tuning of various inverter control parameters. This paper proposes an online impedance measurement technique to capture inverter impedance in the dq-domain. Moreover, the method allows simultaneous measurement of impedance d and q-components. The method is based on the use of orthogonal binary sequences.

**P1705***A New Design Methodology for a 1-Meter Distance, 6.78MHz Wireless Power Supply System for Telemetries [#567]*  
Lee Seung-Hwan, Lee Jun-Ho and Yi Kyong-Pyo   
, University of Seoul, Korea (South); Korea Railroad Rearch Institute, Korea (South)

In this paper, a new large distance, 6.78 MHz, fixed frequency, 50 W output, wireless power transfer system design methodology for telemetries has been proposed. Receiver side tuning topology is selected in the first step of the design methodology. Then, a nominal coupling coefficient between the transmitter and the receiver coil has been calculated using given distance and coil diameters. Feasible ranges of the transmitter and the receiver coil inductances are identified in the following step of the design methodology that satisfy given voltage and current limits. In the feasible design space concept, multiple transmitter and receiver coil geometries are found that result in maximum power transfer efficiency. Then, the control stability, copper weight, volt-amp ratings of the coils are calculated and their contour plots are plotted using the coil geometries. The contour plots show the trade-offs between the system performance and the coil geometry selection. A new variable K is defined in order to find an optimal coil geometry. Using the variable K, the geometries of the transmitter and the receiver are able to be determined. The proposed design methodology is evaluated using an example wireless power transfer system design for an on-line condition monitoring system for a catenary. The efficiency and loss distribution of the designed wireless power system is evaluated by comparison of the theoretical, FEA, and circuit simulation results.

**P1706***Modeling and Investigation of 4-Coil Wireless Power Transfer System with Varying Spatial Scales [#734]*  
Lu Chen, Fuxin Liu, Xinbo Ruan and Xuling Chen   
, Nanjing Univ. of Aeronautics and Astronautics, China

As a mid-range wireless power transfer (WPT) technology, magnetically coupled resonant (MCR) WPT has become a reseach focus in recent years. In this paper, an equivalent circuit model of 4-coil MCR WPT system was presented, along with the formulas of the output power and transmission efficiency. Besides, to comfirm whether spatial misalignments will influence the transmission characteristics of the system, the relationship between the mutual inductance and the spatial misalignments of the coils was analyzed, and the transmission characteristics under various spatial scales was revealed. An experiment circuit was designed and experimental results were well consistent with the theoretical analysis.

**P1707***Vehicular Integration of Wireless Power Transfer Systems and Hardware Interoperability Case Studies [#1356]*  
Omer Onar, Steven Campbell, Larry Seiber, Cliff White and Madhu Chinthavali   
, Oak Ridge National Laboratory, United States

Several wireless charging methods are under development or available as an aftermarket option in the light-duty automotive market. However, there are not a sufficient number of studies detailing the vehicle integration methods, particularly a complete vehicle integration with higher power levels. This paper presents the design, development, implementation, and vehicle integration of wireless power transfer (WPT)-based electric vehicle (EV) charging systems for various test vehicles. Before having the standards effective, it is expected that WPT technology first will be integrated as an aftermarket retrofitting approach. Inclusion of this technology on production vehicles is contingent upon the release of the international standards. The power stages of the system are introduced with the design specifications and control systems including the active front-end rectifier with power factor correction, high frequency power inverter, high frequency isolation transformer, coupling coils, vehicle side full-bridge rectifier and filter, and the vehicle battery. The operating principles of the control, and communications, systems are presented. Aftermarket conversion approaches including the WPT on-board charger (OBC) integration, WPT CHAdeMO integration, and WPT direct battery connection scenarios are described. The experiments are carried out using the integrated vehicles and the results obtained to demonstrate the system performance including the stage-by-stage efficiencies.

Tuesday, September 20, 8:30AM-11:00AM

Photovoltaic Converters I

Tuesday, September 20, 8:30AM-11:00AM, Room: 203AB, Chair: Francisco Canales, Liming Liu

**8:30AM***Low Power Factor Operation of the PV Inverter with Power Decoupling Function [#293]*  
Yusuke Seta and Toshihisa Shimizu   
, Tokyo Metropolitan University, Japan

A novel power conditioner with a power decoupling circuit is proposed in this paper. The proposed power conditioner can generate reactive power for the utility lines. Therefore, the proposed circuit must operate under very low power factors to meet the anti-islanding and fault-ride-through (FRT) functionalities required. In addition, by applying the power decoupling circuit, the current ripple of the DC input side capacitor can be reduced. Therefore, a film capacitor can be used instead of an electrolytic capacitor. The influence of the maximum power point tracking (MPPT) control can be reduced as well. The operating principle, theoretical analysis, and circuit/characteristic simulations of the proposed circuit are described. In addition, the hardware is implemented with a 100-V DC input and a 50-V AC/100-W output to demonstrate its feasibility.

**8:55AM***Stand-Alone Photovoltaic Asymmetrical Cascade Converter [#1115]*  
Alan Felinto, Italo da Silva, Cursino Jacobina, Joao Mello, Isaac Freitas and Nustenil Marinus   
, Federal University of Campina Grande, Brazil; Federal University of Paraiba, Brazil

This paper presents a stand-alone photovoltaic (PV) generation system based on an asymmetric cascade H-bridge (ACHB) converter. The system is composed of two H- bridge converters (A and B) series connected, supplying an ac load. To maximize the number of voltage levels, the dc-link voltage ratio is 3:1. The higher dc- link voltage (converter A) is connected to PV panels, and two options are presented for the lower dc-link voltage (converter B): a battery cluster or a floating capacitor. In addition, two pulsewidth modulation (PWM) strategies are proposed: one is based on phase-shifted carrier (PSC) disposition and the other is based on level-shifted carrier (LSC) disposition. The regulation of the dc-link voltage of converter B is performed with the proposed PWM techniques by changing the power distribution between converters A and B, whereas the dc-link voltage of converter A can be regulated by a feedback controller. Finally, simulation and experimental results are shown for validation purposes.

**9:20AM***Ground Leakage Current Suppression in a 50 kW 5-level T-type Transformerless PV Inverter [#459]*  
Lu Wang, Yanjun Shi, Yuxiang Shi, Ren Xie and Hui Li   
, FSU, United States

In this paper ground leakage current suppression in a 50 kW 5-level T-type transformerless PV inverter has been presented. Compared to a 3-level T-type PV inverter, this topology allows a simple modulation method such as carrier- based (CB) PWM can be used to suppress the leakage current without the penalty of the traditional methods. Phase disposition (PD) and phase opposition disposition (POD) based CB PWM method has been applied to this 5-level topology. The spectrum analysis has demonstrated that PD and POD will generate the same phase voltage spectrum. In addition, the common-mode (CM) voltage of a 5-level T-type PV inverter has been derived and the CM choke has been designed. The value of the CM choke is a 73% reduction compared to that of a 3-level T-type PV inverter. The simulation and experimental verification have been provided.

**9:45AM***A High Performance T-type Single Phase Double Grounded Transformer-less Photovoltaic Inverter with Active Power Decoupling [#1360]*  
Yinglai Xia, Jinia Roy and Raja Ayyanar   
, Arizona State University, United States

Transformer-less PV inverters are gaining widespread applications with lower cost, reduced footprint, and improved efficiency. This paper proposes a topology that can eliminate the common mode leakage current which is a major challenge in transformer-less PV inverters. In addition, an active power decoupling strategy is implemented in this topology instead of using large energy storage element for double line frequency power decoupling, thus achieving a smaller volume. A constant input voltage with negligible double line frequency ripple component ensuring high MPPT efficiency is achieved in this topology. Compared to the previously proposed topology, a T-type branch is added as an improvement to fully take advantage of the inherent three level structure resulting in much reduced switching loss and inductor current ripple. A 1 kW, 100 kHz single-phase prototype with 200 V DC input and 120 V/60 Hz AC output using SiC MOSFETs has been built to validate the theoretical analysis. The control strategy and modulation scheme are implemented in DSP TMS320F28335 resulting in 24% reduction in the total loss and 50% reduction in the inductor current ripple.

**10:10AM***Low Leakage Current Transformerless Three-Phase Photovoltaic Inverter [#1503]*  
Liwei Zhou, Feng Gao, Guang Shen, Tao Xu and Weiqi Wang   
, Shandong University, China; State Grid Rizhao Power Supply Company, China

In a transformerless inversion system, the suppression of common mode leakage current is one of the most important issues concerned. Several single phase full bridge PV inverters have been proposed to eliminate the leakage current. However, in the three phase applications of the PV inverters, few attentions have been paid on the improvement of leakage current from a topological point of view. This paper focuses on the reduction of common mode voltage in three phase transformerless inverter. Firstly, the common mode characteristic of the three phase inverter is analyzed. Then, a kind of novel three phase topology is proposed to suppress the common mode voltage. Also, the NPC circuit can be added to the novel topology in order to further reduce the common mode voltage. The novel topology has the advantages of fewer device cost and lower conduction losses compared to the traditional three phase NPC topologies. Finally, the simulation and experimental results illustrated the theoretical findings.

**10:35AM***Operation of Dual-Input Central Capacitor Photovoltaic Inverter under Unbalanced Grid Voltage Condition [#647]*  
Mengxing Chen, Feng Gao and Chongsheng Jia   
, Shandong University, China

To date, a family of series-connected boost converter (SCBC) with enhanced efficiency has been presented as the front-end dc/dc stage of distributed photovoltaic (PV) inverter, which suffers the severe PV voltage/power oscillation when operated under unbalanced grid voltage condition. This paper proposes an operational scheme to enhance the performance of one type SCBC, namely the dual- input central capacitor (DICC) converter, under unbalanced grid voltage condition. The PV voltage/power oscillation is eliminated using the propose scheme, resulting in the maximum PV energy harvest and enhanced grid current quality even under severe unbalanced condition. Also the overall dc-link voltage oscillation amplitude is minimized. The analytical representation of double line-frequency current along with the DICC circuitry model are studied, so that the DICC circuitry parameters could be designed accordingly. This paper further proposes the control strategy of DICC-PV inverter under unbalanced grid voltage condition. All the theoretical findings and the control method proposed can be derived to other type SCBCs. Finally, the theoretical findings were verified through both Matlab simulation and an experimental prototype.

Modular Multi-Level Converters, HVDC, and DC Grids II

Tuesday, September 20, 8:30AM-11:00AM, Room: 203DE, Chair: Rajib Datta, Ali Mehrizi-Sani

**8:30AM***Impact on Small-Signal dynamics of Using Circulating Currents Instead of AC-Currents to Control the DC Voltage in MMC HVDC Terminals [#1009]*  
Gilbert Bergna, Jon Are Suul and Salvatore D'Arco   
, SINTEF Energy Research, Norway; NTNU / SINTEF Energy Research, Norway

The traditional approach for controlling the dc-voltage in Voltage Source Converter (VSC) HVDC terminals is to act on the reference for the active current or active power on the ac-side. For a Modular Multilevel Converter (MMC) with explicit control of the internally stored energy, this implies that the total energy sum must be controlled by acting on the dc-components of the circulating currents. However, the internal energy storage of an MMC acts as a buffer between the transient dynamics on the ac- and dc-sides. Thus, the dynamic response of the dc-voltage will depend on the closed loop dynamics of the internal energy control. Different system characteristics can be obtained if the reference signals from the dc-voltage control and the sum energy control are interchanged. As a result, the dc-voltage controller can provide the reference value for the dc-components of the circulating current, while the sum energy controller will provide the ac-side active current reference. In this paper, it will be demonstrated by time domain simulations and eigenvalue analysis that dc-voltage control by acting on the circulating current reference introduces a decoupling between the dynamics of the ac- and dc-side interfaces. This decoupling will also make the system dynamics less sensitive with respect to the operating conditions, which enables improved dynamic performances and less strict tuning requirements for the dc-voltage and sum energy controllers.

**8:55AM***Control of VSC-HVDC with Electromechanical Characteristics and Unified Primary Strategy [#1169]*  
Weiyi Zhang, Kumars Rouzbehi, J. Ignacio Candela, Alvaro Luna and Pedro Rodriguez   
, Technical University of Catalonia, Spain; Abengoa, Spain

High voltage dc (HVDC) systems act as the prevailed solution for transmitting offshore wind energy to onshore main grids. Control of the voltage source converters (VSC) in HVDC systems is decisive for the performance. This paper proposes the control of VSC-HVDC with electromechanical characteristics and unified primary strategy, as a reaction to the updated requirements of the ac grid transmission system operators. As two important aspects of VSC-HVDC control, converter control and primary control are both designed in detail. Electromechanical characteristics make the VSC capable of providing inertia to the ac networks as well as simplicity in island operation. Besides, unified primary control is given as a universal primary strategy for VSC stations, and especially takes into account frequency support and control mode transition. The proposed converter control is validated in scaled-down 10 kW laboratory setups, while the proposed primary control is endorsed by the simulation tests on a CIGRE multi-terminal HVDC model.

**9:20AM***A Novel Interline DC Power Flow Controller for Meshed HVDC Grids [#36]*  
Guangfu Ning, Wu Chen and Xu Zhu   
, Southeast University, China

Power flow control ability of meshed high voltage direct current (HVDC) grids can be improved by inserting DC power flow controller into the grids. Based on the study of existing DC power flow controllers, this paper proposes a novel interline DC power flow controller (IDCPFC) which has the benefit of less active switching devices, simpler control, little side effect on meshed grids, no external power source needed and wide application occasions. The performance of the IDCPFC is validated by simulation and experiment tests. The results show that the proposed IDCPFC can achieve stable power flow control in different conditions.

**9:45AM***Impedance-based and Eigenvalue based Stability Assessment Compared in VSC-HVDC System [#650]*  
Mohammad Amin, Atle Rygg and Marta Molinas   
, Norwegian University of Science and Technology, Norway

This paper presents the comparison between the impedance-based and eigenvalue-based stability analysis methods for a VSC-based HVDC system. In order to apply the impedancebased method, an impedance model for the VSCs is analytically derived and the derived model is validated by comparing the frequency responses of the analytical impedance and the impedance measured in a detailed switching model of the VSC-HVDC system. To determine the stability from the eigenvalue based method, an analytical state-space small-signal model is developed and the model is validated by time domain simulations. It is shown that both stability analysis methods can effectively determine the stability of the system. In the case of the impedance- based method, a low phase-margin in the Nyquist plot of impedance ratio indicates that the system can have harmonic oscillation; however the system still operates stably. A weakness of the impedance method is that the stability determined by this method is not a global stability assessment; and it is therefore necessary to investigate the stability at all possible sub/systems. On the other hand, the eigenvalue based method can determine the stability of the entire system; but it cannot predict harmonic oscillations caused by a PWM inverter operating in a stable point. A two terminal VSC-HVDC system has been developed analytically and the frequency domain stability analysis based on impedance and eigenvalues has been carried out. The theoretical analysis has been further validated by simulation and experiments

**10:10AM***Performance Analysis of a Triple-Active Bridge Converter for Interconnection of Future DC-Grids [#942]*  
Markus Neubert, Anton Gorodnichev, Jan Gottschlich and Rik W. De Doncker   
, RWTH Aachen University, ISEA, Germany

Dc-dc converters are a promising technology for interconnection of future dc grids. Besides the relatively low volume and space requirements, dc-dc gonverters provide good controllability of the power flow. This is particularly important with regard to a more decentralized energy generation, where a fully bidirectional power flow - even between grids of equal voltage levels - is desired to increase overall grid efficiency and stability. This paper analyzes the performance of a three-phase triple-active bridge converter (3ph-TAB) which interconnects a 5 kV medium-voltage dc grid and two low-voltage dc grids with nominal voltages of 380V and 760V, respectively. First, the modulation strategy of the converter is described. The different cases of operation are analyzed and a method is developed which significantly simplifies the theoretical analysis of the converter. The design specifications for the leakage inductances of the transformer and the dc-link capacitors are derived and analyzed. Furthermore, the soft-switching boundaries are derived analytically. The theoretical assessment is supported by a semiconductor loss simulation for the whole operating range.

**10:35AM***Dc Fault Protection of Multi-Terminal VSC-HVDC System with Hybrid Dc Circuit Breaker [#1038]*  
Yalong Li, Jin Liu, Xiaojie Shi, Fred Wang and Leon Tolbert   
, University of Tennessee, United States

Dc fault protection is a main challenge in voltage source converter (VSC) based multi-terminal high voltage direct current (HVDC) systems. This paper develops a systematic dc fault protection strategy for systems utilizing hybrid dc circuit breakers as the main protection devices. A two-step fault detection method to accommodate the proactive hybrid dc circuit breaker has been simulated and demonstrated with both fast speed and selectivity. The necessities of temporary blocking HVDC converters for both pole-to-pole and pole-to-ground faults have been evaluated, and the corresponding criteria have been established. In order to achieve fast system recovery after the fault clearance, voltage margin control is proposed to simplify the restart sequence for different converters and reduces the dc voltage variation during the process. The overall protection strategy is demonstrated in a 4-terminal HVDC simulation platform, showing a total dc fault recovery time of around 200 ms.

Renewable Energy II

Tuesday, September 20, 8:30AM-11:00AM, Room: 203C, Chair: Alex.Q Huang, Xueguang Zhang

**8:30AM***Partial Power DC-DC Converter for Photovoltaic String Inverters [#768]*  
Alexander Morrison, Jaime Zapata, Samir Kouro, Marcelo Perez, Thierry Meynard and Hugues Renaudineau   
, Universidad Tecnica Federico Santa Maria, Chile; University of Toulouse, France

In order to increase the conversion efficiency in photovoltaic (PV) systems, different configurations and topologies were developed. Depending on the application, the converters used for grid connection are built using one or two conversion stages. The advantages of the converters with a DC-stage are mainly the distributed maximum power point tracking algorithm per PV string, a wider range of operation, higher energy yield and, when required for grid connection, the possibility of voltage regulation. However, the conversion efficiency is lower than configurations with a single stage as the central inverter. Therefore, the proposed work presents a Partial Power DC-DC converter (PPC) which process part of the entire system power, and the surplus power is directly supplied to the output side. A topology is proposed and the details of its operation are explained based on the operating principle. Simulations are performed in order to evaluate the converter performance.

**8:55AM***On Reactive Power Injection Control of Distributed Grid-tied AC-stacked PV Inverter Architecture [#1502]*  
Hamidreza Jafarian, Babak Parkhideh, Johan Enslin, Robert Cox and Shibashis Bhowmik   
, UNCC, United States; SineWatts, United States

In this paper, two different Reactive Power Injection (RPI) methods for a fully distributed PV inverter architecture are investigated. RPI methods are parts of ancillary service requirements for modern PV systems to play a more active role in grid regulation and control in future high penetrated PV generation networks. The main objective of this paper is to demonstrate and test RPI methods on a panel-level AC-stacked PV-inverter string which is controlled with distributed control scheme with minimum communication requirements and propose a combined RPI method. Effectiveness and feasibility of distributed control architecture and RPI methods are verified by experimental results during normal operation and voltage disturbance conditions using a lab-scale PV inverter string setup.

**9:20AM***A Cost-Effective Power Ramp-Rate Control Strategy for Single-Phase Two-Stage Grid-Connected Photovoltaic Systems [#600]*  
Ariya Sangwongwanich, Yongheng Yang and Frede Blaabjerg   
, Aalborg University, Denmark

In the case of a wide-scale adoption of grid-connected Photovoltaic (PV) systems, more fluctuated power will be injected into the grid due to the intermittency of solar PV energy. A sudden change in the PV power can potentially induce grid voltage fluctuations, and thus challenge the stability of the grid. Hence, this sudden active power change resulting in a large power ramp-rate should be avoided in practice. In fact, some grid regulations also released strict rules on active power ramp-rates for PV systems. This paper proposes a cost-effective control strategy to limit the power ramp-rate for two- stage grid-connected PV systems. The main concept of the proposed scheme is to modify the maximum power point tracking algorithm in such a way to regulate the PV power at the left side of the maximum power point curve. As a consequence, the power ramp-rate can be controlled according to the set-point. Experiments conducted on a 3-kW single-phase two-stage grid-connected PV system have verified that the proposed solution can accomplish fast dynamics, high accuracy, and high robustness in the power ramp-rate control for PV systems.

**9:45AM***Delta Power Control Strategy for Multi-String Grid-Connected PV Inverters [#601]*  
Ariya Sangwongwanich, Yongheng Yang, Frede Blaabjerg and Dezso Sera   
, Aalborg University, Denmark

With a still increasing penetration level of grid-connected PV systems, more advanced active power control functionalities have been introduced in certain grid regulations. A delta power constraint, where a portion of the active power from the PV panels is reserved during operation, is required for grid support (e.g., during frequency deviation). In this paper, a cost-effective solution to realize delta power control for grid-connected PV systems is presented, where the residential/commercial multi-string PV inverter configuration is adopted. This control strategy is a combination of Maximum Power Point Tracking (MPPT) and Constant Power Generation (CPG) modes. In this control scheme, one PV string operating in the MPPT mode estimates the available power, while the other PV strings regulate the total PV power by the CPG control strategy in such a way that the delta power constraint for the entire PV system is achieved. Simulations and experiments have been performed on a 3-kW single-phase grid- connected PV system. The results have confirmed the effectiveness of the delta power control strategy, where the power reserve according to the delta power constraint is achieved under several operating conditions.

**10:10AM***Battery Storage Sizing for a Grid Tied PV System Based on Operating Cost Minimization [#1670]*  
Mohamed Badawy, Fatih Cingoz and Yilmaz Sozer   
, University of Akron, United States

An optimal battery storage sizing is determined for a high power photovoltaic (PV) grid tied system. The sizing of the battery storage is chosen based on an optimal power flow management system intended to minimize the system running cost. Thus, a lower level power flow optimization problem is formulated along with the required constraints. The operating cost in this problem is formulated as a combination of electricity grid prices and the battery degradation cost. In the lower optimization level, forecasted system data is used to find the optimal power management solution for a year long operation. On the higher level, a sizing optimization problem is formulated using the outcomes of the lower level optimization while updating it with the new selected battery size. A case study is applied under various conditions to test the system performance and analyze the necessary storage sizing subjected to different circumstances.

**10:35AM***Dynamic Braking System of a Tidal Generator [#148]*  
Eduard Muljadi, Alan Wright, Vahan Gevorgian, James Donegan, Cian Marnagh and Jarlath McEntee   
, National Renewable Energy Laboratory, United States; Ocean Renewable Power Corporation, United States

The data used in this paper is representative of a typical river or tidal generator. The analysis is based on a generator with a power rating of 40 kW. The tidal generator under consideration is driven by two sets of helical turbines connected to each side of the generator located in between the turbines. The generator is operated in variable speed, and it is controlled to maximize the energy harvested as well as the operation of the turbine generator. The electrical system consists of a three-phase permanent magnet generator connected to a three-phase passive rectifier. The output of the rectifier is connected to a DC-DC converter to match the rectifier output to the DC bus voltage of the DC-AC inverter. The three-phase inverter is connected to the grid, and it is controlled to provide a good interface with the grid. One important aspect of river and tidal generation is the braking mechanism. In a tidal generator, the braking mechanism is important to avoid a runaway condition in case the connection to the grid is lost when there is a fault in the lines. A runaway condition may lead to an overspeed condition and cause extreme stresses on the turbine blade structure and eventual disintegration of the mechanical structure. In this paper, the concept of the dynamic braking system is developed and investigated for normal and abnormal operations. The main objective is to optimize the performance under emergency braking while designing the system to be as simple as possible to avoid overdesigning the power electronics or exceeding the target budget.

Utility Applications I

Tuesday, September 20, 8:30AM-11:00AM, Room: 202A, Chair: Hirofumi Akagi, Rajasekharareddy Chilipi

**8:30AM***Multi-frequency Power Routing for Cascaded H-Bridge Inverters in Smart Transformer Application [#655]*  
Youngjong Ko, Markus Andresen, Giampaolo Buticchi, Luca Concari and Marco Liserre   
, Christian-Albrechts-University, Germany; University of Parma, Italy

The smart transformer is a solid state transformer with advanced control functionalities that can efficiently manage a low-voltage micro-grid by also supporting the medium-voltage grid. Cascaded H-bridge (CHB) converters proved to be a suitable option to realize the MV stage of the smart transformer due to their modularity and multi-level output. Normally the power is equally split among the CHB cells, however, in order to delay failures of the system, certain cells can be unloaded if premature deterioration is detected. In this work, multi-frequency power transfer is used to control the power processed by the dc/dc converters that supply the dc link of the CHB. The potential is analyzed analytically and validated experimentally.

**8:55AM***A High Power Medium Voltage Resonant Dual Active Bridge for DC Distribution Networks [#973]*  
Mohammed Agamy, Dong Dong, Luis J. Garces, Yingqi Zhang, Mark Dame, Ashraf Said Atalla and Yan Pan   
, GE Global Research Center, United States; GE Global Research Center, China

This paper presents a megawatt scale, medium voltage, medium frequency resonant dual active bridge dc-dc converter operating as a bus-tie converter in a dc distribution network. The high voltage side of the converter is designed using series connected low voltage devices in order to efficiently operate at higher switching frequencies. A combined variable frequency and phase shift control method is propsed to achieve input/output power flow and voltage control, while maintaining soft switching operation for both high voltage and low voltage bridges. A 1MW converter prototype is presented to validate the proposed topology and control.

**9:20AM***Mu synthesized robust controller for multi-SST islanded smart grid [#848]*  
Tong Yao, Isaac Leonard, Raja Ayyanar and Konstantinos Tsakalis   
, Arizona State University, United States; Florida State University, United States

This paper introduces a robust controller design method for maintaining microgrid operation under grid islanded mode by solid state transformers (SST) using master-slave control strategy. In the grid islanded mode, the grid voltage controller of the master SST, designed using Mu synthesis, ensures stable control of the microgrid voltage. This paper extends the uncertainty modeling to general grid impedance uncertainties, slave SST current command uncertainties and master SST DC link voltage uncertainties. Also, the proposed design method is general and flexible enough to be readily scaled for applications in larger power systems. A three-SST system is used to demonstrate the design method with twelve uncertainties modeled. The designed system stability and performance robustness are validated in Mu analysis, PLECS simulation, and a controller-hardware-in-the-loop (CHIL) test bed with a Real-Time Digital Simulator (RTDS).

**9:45AM***Cascaded Open-End Winding Transformer based DVR [#767]*  
Gregory Carlos, Cursino Jacobina, Euzeli Dos Santos Jr. and Joao Mello   
, Federal Institute of Alagoas - IFAL, Brazil; Federal University of Campina Grande - UFCG, Brazil; Indiana University-Purdue University Indianapoli, United States

This paper introduces and generalizes a class of multilevel dynamic voltage restorer (DVR) for voltage sags/swells compensation of high-power sensitive loads. Two DClinks can provide either symmetrical (i.e., equal DC-link voltages) or asymmetrical (i.e., different DC-link voltages) operation of the DVR converters. Generalization for K-stages is presented as well. The proposed configuration is named as DVR-COEW (i.e., cascaded open-end winding). The topology permits to generate a maximized number of voltage levels per converter leg. The multilevel waveforms at the output voltages of the converter are generated by using a suitable PWM strategy associated with both: i) DC-link voltages ratio and ii) transformers turns ratio. The model and PWM control are addressed in this paper. Simulation and experimental results are presented.

**10:10AM***Modeling and Control of Gan Based Multiport Power Converter [#1488]*  
Mohammed Alsolami, Xuan Zhang, Karun Potty and Jin Wang   
, King Abdulaziz University, United States; The Ohio State University, United States

This paper presents the small-signal modeling and controller design of a single phase multilevel, three-port based on gallium nitride (GaN) devices for renewable energy and UPS applications. The system has two ac-port with five-level waveforms and one DC port. A small-signal model of the converter is derived by the method of state-space averaging. It is controlled with two loops, an outer voltage controller is designed to regulate the DC link voltage and inner control loop compensates the grid current to track the step change in the load current. Comparison of the close-loop simulation from the derived small-signal model and a detailed circuit model showcases the effectiveness of the small signal model. Closed loop simulation results from both the small-signal model and the detail circuit model are presented and experimental results are provided.

**10:35AM***Economic Feasibility Analysis and Operational Testing of a Community Energy Storage System [#402]*  
Ben Knueven, Jim Ostrowski, Ben Ollis, Philip Irminger, Michael Starke, Andrew Herron, Dan King, Bailu Xiao, Yaosuo Xue, Peter Karlson, Christine Labaza, David Maxwell, Seelan Thambiappah, Pablo Valencia and Sebastien Massin   
, University of Tennessee - Knoxville (UTK), United States; Oak Ridge National Laboratory (ORNL), United States; General Motors Company, United States; ABB, United States

A study of the impact of utility rates on the economic viability of Community Energy Storage (CES) is presented in this paper. Using the U.S. Utility Rate Database, the residential rate structures available at each available zip code in the continental United States were analyzed to see how viable CES is for that zip code. An operational CES hardware system was also tested to verify the results from economic analysis for the specific regions.

Electric Machines for Transportation Electrification

Tuesday, September 20, 8:30AM-11:00AM, Room: 102D, Chair: Akira Chiba, Emmanuel Agamloh

**8:30AM***Electrical machine acoustic noise reduction based on rotor surface modifications [#120]*  
Andreas Andersson and Torbjorn Thiringer   
, Volvo Car Group, Sweden; Chalmers Univeristy of Technology, Sweden

Electromagnetic acoustic noise from electrical machines has increasingly become an area of attention for both academia and industry. In electric propulsion systems, this is a main contributor to the total acoustic noise and it is usually perceived as annoying due to its tonal appearance. This paper presents an alternative rotor design for a permanent magnet synchronous machine with the objective to decrease prominent machine orders in the acoustic noise by force density harmonics minimization. Apart from this, torque characteristics and core losses are included in the study as well, in order to investigate possible adverse effects. In the proposed design, irregularities are introduced in the rotor surface to suppress harmonics in the flux density by locally altering the airgap permeance. The analysis is based on finite element modeling, using a sequentially solved, weak coupled, multi-physics approach which enables separation of the electromagnetic-, structural dynamical- and acoustic problems. The results show that the most prominent harmonics in the acoustic noise can be reduced without significantly deteriorating the dynamic performance. It is also demonstrated that the core losses of the machine is positively affected by the obtained harmonic magnitude reduction in the flux density. Although the paper focuses on minimization of radial force density harmonics, the results indicate that the approach and the methodology may also be used for torque harmonics minimization.

**8:55AM***Integrated Control of an IPM Motor Drive and Hybrid Energy Storage System for Electric Vehicles [#1663]*  
Mohamed Badawy, Tausif Husain and Yilmaz Sozer   
, University of Akron, United States

A DC bus voltage control for a motor drive is proposed in this paper using a hybrid energy storage system (HESS) composed of a battery and an ultra- capacitor for electric vehicle applications. The motor drive of an interior permanent magnet (IPM) motor is typically developed based on a fixed DC bus voltage. However, with the voltage controllability of HESS, it is possible to optimize the energy system by selecting the optimum DC bus voltage. Unlike the conventional designs, the proposed HESS processes only a portion of the vehicle power through interfacing a DC/DC converter. The new concept reduces the converter losses, enables the full usage of stored energy in the storage units and provides a boosting capability of the DC bus voltage. This capability allows the motor drive to operate with maximum torque per ampere control for longer time intervals. An EV with HESS and an IPM drive is simulated under different driving conditions to demonstrate the concept. Experimental results of a scaled down system are provided.

**9:20AM***Investigation and Analysis of Temperature Effects on Interior Permanent Magnet Machines [#1333]*  
Silong Li, Bulent Sarlioglu, Sinisa Jurkovic, Nitin Patel and Peter Savagian   
, University of Wisconsin-Madison, United States; General Motors Comapany, United States

The purpose of this paper is to analyze and investigate the influence of temperature variation on the characteristics and performance of interior permanent magnet (IPM) machines. The impact of temperature variation on the materials of IPM machines is discussed to show the sources of performance variation. The flux linkages and torque output capability variation as functions of the temperature of are analyzed and discussed. The paper also shows the influence of temperature variation on key IPM machines performance including constant torque curves, voltage limit ellipses, maximum torque per ampere and maximum torque per volt trajectories and torque-speed curves. The results and trends shown in this paper set a foundation for developing control algorithm which takes the temperature effects into consideration, especially in the applications where operating temperature varies significantly.

**9:45AM***A Novel Flux-Switching Permanent Magnet Motor-Compressor with Integrated Airfoil-Shaped Rotor Design [#1320]*  
Yingjie Li, Dheeraj Bobba, Erik Schubert, Hao Ding, Casey Morris and Bulent Sarlioglu   
, Electrical and Computer Engineering, UW-Madison, United States

The purpose of this paper is to propose a novel fluxswitching permanent magnet motor with an integrated airfoilshaped rotor. Some of the conventional axial-flow compressor systems need an electric motor to provide mechanical energy input to the compressor. The proposed novel flux-switching motor-compressor can integrate both an electric motor and an axial-flow compressor into a single entity and perform axialflow compression using the airfoil-shaped rotor. This integrated motor-compressor design eliminates the connection between the electric motor and compressor and makes the entire system more compact. Due to the high-speed nature of the integrated motor, no gearbox is needed in the proposed design so that reliability is improved. The principle of design for the proposed integrated motor-compressor is discussed. Analytical studies for the thermodynamics and electromagnetics are elaborated in this paper. A case study design is done to investigate the effect of rotor airfoil curvature to the torque production capability, and the results are demonstrated by finite element analysis.

**10:10AM***Novel 6-Slot 4-Pole Dual-Stator Flux-Switching Permanent Magnet Machine Comparison Studies for High-Speed Applications [#1336]*  
Yingjie Li, Ju Hyung Kim, Riccardo Leuzzi, Mingda Liu and Bulent Sarlioglu   
, Electrical and Computer Engineering, UW-Madison, United States; Elec. and Info. Engineering, Politecnico di Bari, Italy

This paper presents the study on a novel dual-stator 6/4 flux-switching permanent magnet (FSPM) machine for highspeed applications. Three different alternative topologies of dualstator 6/4 FSPM machines are proposed and their performances regarding flux linkage, back electromotive force (back-EMF), torque density, and manufacturability are compared to the same specification of 10 kW and 15,000 rpm condition. Design considerations for each of the proposed topology are elaborated. The proposed dual-stator 6/4 FSPM machine is compared with the conventional 12/10 FSPM machine designed at the same power and speed rating. Results show that the proposed low-pole dual-stator 6/4 FSPM machine achieves a significant reduction of high-frequency losses including iron loss and magnet eddy current loss than the high-pole 12/10 FSPM machine. Thus the dual-stator 6/4 FSPM machine is more amenable for high-speed operation than the 12/10 FSPM machine because of less fundamental frequency required, less total loss, and more energy savings.

**10:35AM***High-Specific-Power Electric Machines for Electrified Transportation Applications - Technology Options [#1072]*  
Xiaolong Zhang and Kiruba Sivasubramaniam Haran   
, University of Illinois, Urbana-Champaign, United States

Specific power of an electric machine is defined as the ratio of output power to total weight. High-specific-power (HSP) electric machines are in high demand in electrified transportation systems such as more electric aircraft (MEA) and electric vehicles (EV), because they help reduce the fuel consumption and extend the traveling range. However, electromagnetic, thermal, mechanical and manufacturing issues put limits on the machines' specific power and represent major technological challenges in their design and fabrication. This paper provides a survey of actual HSP machines and discusses design considerations and technology options for HSP machine development. An HSP permanent magnet synchronous machine architecture is proposed based on the survey and discussions.

Multilevel Converter Applications

Tuesday, September 20, 8:30AM-11:00AM, Room: 202E, Chair: Giri Venkataramanan, Qin Lei

**8:30AM***A Fully FPGA-Based Real-time Simulator for the Cascaded STATCOM [#947]*  
Jianxin Zhu, Guodong Teng, Yang Qin, Daorong Lu, Haibing Hu and Yan Xing   
, Nanjing Univ. of Aeronautics and Astronautics, China

A real-time simulation for the Cascaded STATCOM fully implemented on field-programmable-gatearrays(FPGA) is proposed in this paper. The switchingfunction model for the STATCOM is employed, where the IGBTs and diodes are taken as ideal switches, to reduce the amount of calculation. With the help of external circuit calculation, the operation in dead-time period is taken into consideration, which makes all of the operation modes covered. To eliminate the reverse current of diode in discretized simulation, a simple measure and approximation is taken by setting the negative calculated current zero. Full parallelism and deep pipelining are employed in FPGA implementation to minimize the latency. To make a full comparison, a Simulink-based STATCOM model and a 30A 380V scale-down STATCOM prototype were built respectively. The simulation and experiment show that the results from real-time simulator match those from Simulink model and the prototype pretty well, which demonstrate the effectiveness of the proposed real-time simulator for the Cascaded STATCOM.

**8:55AM***A Broad Range of Speed Control of a Permanent Magnet Synchronous Motor Driven by a Modular Multilevel TSBC Converter [#1319]*  
Wataru Kawamura, Yuto Chiba and Hirofumi Akagi   
, Tokyo Institute of Technology, Japan; Komatsu Limited, Japan

This paper provides a theoretical and experimental discussion on a modular multilevel triple-star bridge-cell (TSBC) converters. This paper also proposes a new control method for mitigating ac voltage fluctuation of the dc capacitor of each bridge cell. The proposed method is characterized by properly injecting both common-mode voltage and circulating currents to each cluster in the whole speed range. Moreover, this paper attempts to optimize the amplitude and frequency of the sinusoidal common-mode voltage with help of numerical analysis. This makes the ac voltage fluctuation the smallest. The new method can reduce both voltage fluctuation and cluster current more effectively than existing methods. Experimental waveforms using 370-V, 75-Hz, 15-kW interior-permanent magnet synchronous motor loaded at the rated torque show good start-up performance from a standstill to the rated speed, keeping both capacitor-voltage and cluster current within acceptable levels.

**9:20AM***Comparison of SiC and GaN Devices for Front-End Isolation of Quasi-Z-Source Cascaded Multilevel Photovoltaic Inverter [#1065]*  
Yushan Liu, Baoming Ge, Haitham Abu-Rub, Haiyu Zhang and Robert S. Balog   
, Texas A and M University at Qatar, Qatar; Texas A and M University, United States

The wide band-gap Silicon Carbide (SiC) and gallium nitride (GaN) materials based semiconductor devices have attracted tremendous attentions in modern power electronics applications. They provide much higher switching frequency and higher junction temperature than silicon power devices, thus to significantly decrease the system volume and weight, especially on passive components. In this paper, the characteristics of the SiC and GaN materials and devices are overviewed. A front-end isolated quasi-Z-source cascade multilevel inverter (qZS-CMI) based Photovoltaic (PV) power system is proposed to insulate the PV array from high voltage grid and make possible of PV grounding, thus to enhance the system reliability and safety. The SiC and GaN devices applied to the front-end isolation of qZS inverter module are compared. Experimental results verify the proposed front-end isolated qZS-CMI and comparison results, demonstrating a competitive solution for the future development of such inverters.

**9:45AM***Which is more suitable to a Modular Multilevel SDBC Inverter for Utility-Scale PV Applications, Phase-Shifted PWM or Level-Shifted PWM? [#887]*  
Paul Sochor and Hirofumi Akagi   
, Tokyo Institute of Technology, Japan

This paper discusses and compares phase-shifted pulsewidth modulation (PS-PWM) and level-shifted PWM (LSPWM) in a modular multilevel single-delta bridge-cells (SDBC) inverter for utility-scale grid-tied photovoltaic (PV) applications. A unique characteristic of this inverter application is the capability to operate even under imbalanced power distribution among its bridge cells. An imbalanced energy distribution may degrade harmonic performance and limit the inverter operating range. The focus of this research lies in analyzing the following two fundamental properties; waveform quality and energy balancing capability when either PS-PWM or LS-PWM is applied. This paper highlights the benefits of LS-PWM over PS-PWM in this particular application, and demonstrates that the SDBC inverter is suitable for applications with imbalanced power distribution. Experimental results obtained from a three-phase 10-kW downscaled SDBC inverter with six bridge cells per cluster show good agreement with those from theoretical analysis.

**10:10AM***A Symmetrical Hybrid Nine-Level Inverter for High Speed Open-Winding Motor Drive System [#1271]*  
Kui Wang, Yongdong Li, Zedong Zheng, Dabo Wei and Boran Fan   
, Tsinghua University, China

In order to reduce output voltage harmonics and improve efficiency, a symmetrical hybrid nine-level inverter for high speed open-winding motor drive system is presented in this paper. Each phase of this inverter is composed of a five-level DC/DC converter and an H-bridge. The DC/DC converter is operated at high frequency with low voltage MOSFETs and the H-bridge is operated at fundamental frequency with high voltage IGBTs. The three phases are connected to a common DC-link and each drives an isolated winding of an open-winding motor. The operating principles and modulation method is introduced. A detailed analysis of the average currents through the flying capacitor and neutral point of the DC-link is presented and a capacitor voltage balancing method is proposed. Experimental results are presented to demonstrate the feasibility of this inverter.

**10:35AM***Control of Neutral-Point Voltage in Three-Phase Four-Wire Three-Level NPC Inverter Based on the Disassembly of Zero Level [#717]*  
Chenchen Wang, Xiahe Si and Hongliang Xin   
, Beijing Jiaotong University, China

The neutral-point voltage balancing problem is a key issue for three-level three-leg neutral-point clamped (NPC) inverter used in three-phase four-wire system. In this paper, a detailed discussion on this issue and a mathematical model for the neutral-point voltage fluctuation are given. Then a novel neutral- point voltage control strategy based on the disassembly of zero level is proposed. To balance the neutral-point voltage, a variable which can depict the disassembly margin of each phase, named neutral point control margin (NPCM) is defined. The duty ratio of zero level in the phase selected on the basis of NPCM is decomposed to positive and negative level equivalently in order to balance the neutral-point voltage while the average value of the output voltage is preserved unchanged. Furthermore, the relationship between the proposed control strategy and the existing method based on 3-D space vector modulation (3DSVM) in a-b-c coordinates is analyzed. It is showed that the proposed control strategy is superior in simplifying the algorithm and improving the control performance compared with the 3DSVM method. The proposed control strategy is verified by simulation and experiment.

Modeling and Control of DC-DC Converters I

Tuesday, September 20, 8:30AM-11:00AM, Room: 102C, Chair: Johann Walter Kolar, Juan Rivas-Davila

**8:30AM***Observer-based Nonlinear Control for Frequency Modulated Dual-Active-Bridge Converter [#1231]*  
Duy-Dinh Nguyen, Manh-Linh Nguyen, Tuyen Nguyen-Duc and Goro Fujita   
, Shibaura Institute of Technology, Japan; Tokyo University of Sience, Japan

This paper proposes a nonlinear control system based on a nonlinear observer to manage the active and reactive power within a single-phase-frequency- modulated Dual-Active-Bridge DC/DC converter directly. It is accomplished by employing a nonlinear controller to regulate the direct and quadrature current, id(t) and iq(t), as they are directly proportional to two power components, respectively. A nonlinear observer is designed to detach two current components from the average absolute value irec,avg of the transferred current. Since irec,avg is a DC quantity, very high sampling frequency is not required allowing to use the popular DSP, such as TMS320F28335, for processing. Experiment results show that the performance of the observer is fine when the converter operates under soft-switching condition which is achieved by assigning a positive value for the quadrature current iq(t). Under such condition, the amplitude error is in the range of 1% while the absolute load angle error is less than 2 degrees in the scale of 360 degrees for one switching cycle . In term of control stability, id(t) and iq(t) are well regulated by the nonlinear controller at any desired values.

**8:55AM***Novel Control Architecture for Dual Output DC-DC Converter Driving DC-AC Inversion System [#140]*  
Zhi Geng, Dazhong Gu and Dariusz Czarkowski   
, NYU Tandon School of Engineerig, ECE Department, United States

To interface low-voltage dc-output power sources to ac grid, the split dc-bus dc-ac inverters driven by step-up isolated dual-output dc-dc converters can be a solution. When the split dc-bus dc-ac inverter is loaded with single-phase ac or unbalanced three-phase ac, current ripples will propagate through the dc-dc converters at frequencies that are related to the ac side fundamental. For the dc-dc converter close-loop voltage regulation to be robust against the disturbance introduced by those low frequency current ripples, a novel control architecture is proposed. In this paper, a combined control structure for dual-output dc-dc converters with common mode (CM) and differential mode (DM) compensation loops are presented. Simulation and experimental results have been provided for validation.

**9:20AM***Dynamic Bus Voltage Control for Light Load Efficiency Improvement of Two-stage Voltage Regulator [#794]*  
Chao Fei, Mohamed Ahmed, Fred Lee and Qiang Li   
, CPES - Virginia Tech, United States

The two-stage 48V-12V-1.8V Voltage Regulator Module (VRM) structure is gaining more and more attention in high-end server applications. The LLC converter is the preferred choice for the first conversion stage because it provides the isolated 12V output efficiently, which is then converted to 1.8V by the multi-phase Buck converter. Since the CPU works in sleep-mode most of the time, the light load efficiency is very important for energy saving. This paper proposes to change the primary side of the LLC converter from the full-bridge configuration into the half-bridge configuration dynamically in the light load condition, so that the output of the LLC DC Transformer (DCX) can be changed from 12V to 6V. This will increase the overall light load efficiency significantly due to the reduced core loss of the LLC DCX and the reduced switching loss of the multi-phase Buck converter. To achieve a fast transition of the bus voltage between 12V and 6V, the capacitance for the intermediate bus is properly selected and the Optimal Trajectory Control (OTC) for transition between the full-bridge and half-bridge is proposed. A high-efficiency, high-density 48V-12V/6V LLC DCX is designed, and experimental results on the two-stage VRM demonstrate that there is a fast transient response and a more than 10% light load efficiency improvement.

**9:45AM***A Novel Large-Signal Stability Analysis Approach Based on Semi-Tensor Product of Matrices With Lyapunov Stability Theorem Using for DC-DC Converters [#1245]*  
Hong Li, Fang Ren, Bo Zhang, Jianing Shang, Jinhu Lv and Hongsheng Qi   
, Beijing Jiaotong University, China; South China University of Technology, China; Chinese Academy of Sciences, China

Due to the nonlinearity of DC-DC converters,small-signal methods do not guarantee the stability of DC-DC converters under any large-signal disturbances. In this paper,semi-tensor product of matrices with Lyapunov stability theorem is firstly adopted for analyzing the large-signal stability of DC-DC converters. A buck converter with proportional-integral (PI) controller is used as an example. Based on the Lyapunov stability theorem and the state equation of the buck converter, a positive definite Lyapunov function including a nonlinear integral of type Lurie is adopted in this paper. Moreover, the large-signal stability criteria of the buck converter, namely, the condition for ensuring the negative definiteness of the derivative of the Lyapunov function is obtained based on semi-tensor product of matrices. Finally, simulation and experimental results are given to verify the correctness of the large-signal stability analysis approach based on semi-tensor product of matrices with Lyapunov stability theorem.

**10:10AM***A Study on the Control Loop Design of Non-Isolated Configurations for Hybrid Storage Systems [#1159]*  
Ramy Georgious, Jorge Garcia, Angel Navarro-Rodriguez and Pablo Garcia   
, University of Oviedo, Spain

This work focuses on the control strategies for different configurations of Non-Isolated Hybrid Energy Storage Systems. Basic strategies are proposed, studied and compared. Parting from the standard parallel connection of bidirectional boost converter in hybrid storage systems, a comparison with alternate topologies is presented. These alternative schemes overcome the problems that arise in the original configuration due the high mismatch in voltage ratings of the individual storage systems. A strategy to design the control loops of the resulting Hybrid Energy Storage System is proposed, studied, simulated and experimentally implemented on a 1.5 kW demonstrator. The control strategy is implemented in the standard bidirectional boost converter approach and also in the series-parallel connection of the storage units. The reported results show how the proposed control strategy applied to the series parallel connection presents a good performance in terms of dynamic and steady state operation.

**10:35AM***Effects of Non-Ideal Compensators for the High-Bandwidth Low-Standby-Power Computer V-Core Converter Applications [#576]*  
Ching-Wei Yin, Dan Chen, Sheng-Fu Hsiao, Ching-Jan Chen and Hung-Shou Nien   
, EE, National Taiwan University, Taiwan; Richtek Technology Corporation, Taiwan

The stringent requirements on both the control bandwidth and the supply standby current make it tough to design the IC controllers for the v-core converters in future computer applications. The effects of the non-ideal characteristics of the finite gain-bandwidth product and non-zero output impedance of an operational amplifier (OP) are investigated for such a purpose. The results show surprising behavior, including the possibility of generating new complex poles and a positive zero in the compensator gain transfer function. That may affect the converter feedback stability margin. Increasing the OP bandwidth performance may alleviate this problem but that is usually achieved at the expense of supply standby power which is increasingly a critical consideration. The results developed in this paper allow better optimization of the OP used in a controller IC. Several commonly-used compensator types are analyzed. Simulations and experimental results are used for verification. Two practical DC converter examples are used for illustration.

Modulation Techniques I

Tuesday, September 20, 8:30AM-11:00AM, Room: 102E, Chair: Suman Debnath, Liliana de Lillo

**8:30AM***A Unified SVM Algorithm for Lifetime Prolongation of Thermally-Overheated Power Devices in Multi-Level Inverters [#1687]*  
Mokhtar Aly, Gamal M. Dousoky, Emad M. Ahmed and Masahito Shoyama   
, Kyushu University, Japan; Minia University, Egypt; Aswan University, Egypt

This paper presents a unified space vector modulation (SVM) algorithm for lifetime prolongation of thermally-overheated power semiconductor devices in multilevel inverters. Thermal overheating is the main cause of shortenedlifetime and open-circuit faults of the devices. Power semiconductor devices are subjected to thermal overheating due to their ageing that results from continuous overloading and power cycling. Moreover, thermal overheating in high power devices may result from its degradation and faults in the cooling system. When a thermal overheating is detected in one of the power devices, the proposed algorithm is applied to relieve the overheated device and dangerous circumstances are avoided as a result. The proposed algorithm relies on using the redundancy property between switching states in multilevel inverters to continuously evaluate a cost function of the junction temperature of thermally-overheated device for all possible switching sequences set, then it identifies the optimal relieving switching sequence. The proposed unified SVM is general that can be applied to any multilevel inverter, and also is valid for switching devices, as well as DC-link capacitors. The proposed algorithm has been designed and validated by simulation and experimental prototypes of three-level T-type inverter.

**8:55AM***Pulse-Width Modulation Strategy in Double-Delta Sourced Windings [#410]*  
Yongsoon Park and Seung-Ki Sul   
, Samsung Electronics, Korea (South); Seoul National University, Korea (South)

A topology, so called, Double-Delta Sourced Winding(DDSW) has been proposed to improve harmonic properties in highpowerconversion systems. In this paper, a pulse-width modulationmethod is proposed to further optimize the harmonic properties inDDSW-based systems. Specifically, it is described throughmathematical analyses how to modify voltage references forreducing harmonics in combination with DDSW. The effectivenessof the proposed method is assessed with experimental results. As aresult, the proposed method revealed 40% further reduction ofharmonic current.

**9:20AM***A Quasi-Periodic Modulation Strategy to Mitigate EMI for a GaN-based Quasi-Z-Source DC-DC Converter [#13]*  
Saad Ul Hasan and Graham E. Town   
, Macquarie University, Australia

Wide-bandgap (WBG) switching devices, such as gallium nitride (GaN), enable switching at high frequencies with low rise and fall times. This provides advantages such as high power density and compact size, however a potential unwanted side-effect is increased electromagnetic interference (EMI) because of large transient currents. A novel quasi-periodic modulation scheme is described for voltage-fed quasi-Z-source (qZS) DC-DC converters which substantially reduces the peak EMI. The driver logic required is simple and generic, and therefore adaptable to all modulation schemes proposed to date for isolated qZS DC-DC converters. Various experimental results verify the effectiveness of the proposed strategy in terms of voltage gain, efficiency and EMI suppression.

**9:45AM***A General Space Vector PWM Scheme for Multilevel Inverters [#1214]*  
Fa Chen and Wei Qiao   
, University of Nebraska-Lincoln, United States

This paper proposes a new general space vector pulse-width modulation (SVPWM) scheme for multilevel inverters with any voltage levels. The proposed SVPWM scheme calculates the duty cycles and switching states based on the modulation triangle quickly identified through a simple coordinate transformation; no prestored memory-consuming lookup table or time-consuming iterative calculation is required. Therefore, the proposed general SVPWM is computational efficient. Simulation and experimental results are provided to validate the proposed SVPWM scheme.

**10:10AM***Suppression of Common Mode Circulating Current for Modular Paralleled Three-phase Converters based on Interleaved Carrier Phase-shift PWM [#619]*  
Zhongyi Quan and Yun Wei Li   
, University of Alberta, Canada

Circulating current has been the major concern for the implementing of paralleled converters. Extensive studies have been conducted in reducing the circulating current with different modulation strategies. However existing methods are either suffering from poor performances or too complicated for implementation. This paper proposes an interleaved carrier phase-shift (ICPS) PWM to reduce the peak value of the high frequency common mode circulating current (HF- CMCC). The proposed method can be used in the system with arbitrary number of VSCs, which makes the method very suitable for modular design. In addition, the ICPS PWM is very simple for implementation. Theoretical analysis is presented in this paper to explain the effectiveness of ICPS PWM on CMCC peak value reduction. The proposed method has been verified and compared with the interleaved SPWM (ISPWM) in simulation and experiment.

**10:35AM***Modulation Strategies for Three-Phase AC-DC Matrix Converters: a Comparison [#1199]*  
Michele Mengoni, Luca Zarri, Angelo Tani, Giovanni Serra, Domenico Casadei and Gabriele Rizzoli   
, University of Bologna, Italy

The matrix converter rectifier is an AC-to-DC converter that can be considered for emerging applications, related to smart grids and renewable energy production. The most attractive characteristics of this converter are the simultaneous control of the input power factor and the output voltage, and the small volume of the input capacitors. In this paper, after a small review of the modulation techniques, several modulation strategies are experimentally compared in terms of power losses and THD of input and output currents.

Model Predictive Control of Power Converters

Tuesday, September 20, 8:30AM-11:00AM, Room: 202D, Chair: Po-Tai Cheng, Petros Karamanakos

**8:30AM***Constrained Long-Horizon Direct Model Predictive Control for Power Electronics [#787]*  
Petros Karamanakos, Tobias Geyer and Ralph Kennel   
, Technical University of Munich, Germany; ABB Switzerland LTD., Corporate Research, Switzerland

The direct model predictive control (MPC) problem for linear systems with integer inputs, such as many power electronic systems, can be formulated as an integer least-squares (ILS) optimization problem. However, solving this problem when state and/or output constraints are explicitly included is challenging. In this paper, a method that allows to effectively use the sphere decoder---even in the presence of the aforementioned constraints---is proposed. This is done by computing a new hypersphere based on the feasible control input set, as defined by the imposed state/output constraints. A variable speed drive system with a three-level voltage source inverter serves as an illustrative example to demonstrate the performance of the proposed algorithm.

**8:55AM***Thermal-based Finite Control Set Model Predictive Control for IGBT Power Electronic Converters [#1086]*  
Johannes Falck, Markus Andresen and Marco Liserre   
, Kiel University, Germany

Thermal cycling is one of the main sources of aging and failure in power electronics. A possibility to reduce the thermal stress of semiconductors is to control the losses occurring in the semiconductor devices with the target to reduce the thermal cycles. This approach is known as active thermal control. The hardest limit of the existing active thermal control approaches is that they do not offer a general framework where the optimal switching sequence is selected in order to fulfill the applications demand and reduce the thermal stress in specific semiconductors. The goal is to achieve the minimum thermal stress for the best possible overall performance. For this purpose finite control-set model predictive control (FCS-MPC) seems the optimal approach because it allows including of non-linear thermal and lifetime related models into the control law. A precise control of the thermal stress in the semiconductors can be achieved as the optimal switching vector is directly applied to the physical system. This allows to avoid overrating of the used module or to increase its lifetime. In the paper the approach is proven using simulation and experimental results.

**9:20AM***Modulated Model Predictive Control for Active Split DC-bus 4-leg Inverters [#1697]*  
Stefano Bifaretti, Luca Tarisciotti, Alessandro Lidozzi, Sabino Pipolo, Luca Solero and Pericle Zanchetta   
, University of Rome Tor Vergata, Italy; University of Nottingham, United Kingdom; Roma Tre University, Italy

This paper proposes a Predictive Control, formally Dead-Beat (DBC), for a four-leg inverter having an Active Split DC-bus on the fourth leg and LC filters on phase-to-neutral outputs. Such a configuration permits to reduce the voltage ripple on the neutral point connected to inverter grounding. As only few control techniques have been investigated for Active Split DC-bus, the paper proposes to investigate the performance of DBC, which has been widely used for other power electronics applications. The main advantage of DBC over the classical PI or Resonant controller is that no tuning is required for control loop, while obtaining very fast transient response as well it can handle general constrained nonlinear systems with multiple inputs and outputs in a unified and clear manner. These features are highly valuable in power electronic converters used to supply the electrical utility loads in micro-grids. However, one of the main drawback of the DBC is the limited capabilities on harmonics compensations required when supplying unbalanced and non-linear loads. The paper presents continuous-time and discrete-time models of DBC applied to a four-leg VSI with Active Split DC-bus, highlighting the performance through simulation results as well as experimental tests.

**9:45AM***Computationally Efficient Sphere Decoding for Long-Horizon Direct Model Predictive Control [#785]*  
Petros Karamanakos, Tobias Geyer, Toit Mouton and Ralph Kennel   
, Technical University of Munich, Germany; ABB Switzerland LTD., Corporate Research, Switzerland; Stellenbosch University, South Africa

In this paper we present a computationally efficient implementation of the sphere decoder, which is employed to solve the integer least-squares (ILS) problem underlying direct model predictive control (MPC) for power electronic applications. The introduced modifications take advantage of the structure of the problem and, as a result, the required real-time operations can be reduced to a minimum. The efficacy of the developed algorithm is demonstrated with a variable speed drive system with a three-level voltage source inverter.

**10:10AM***Fixed Frequency Finite-State Model Predictive Control for Indirect Matrix Converters with Optimal Switching Pattern [#1170]*  
Jiaxing Lei, Luca Tarisciotti, Andrew Trentin, Pericle Zanchetta, Patrick Wheeler and Andrea Formentini   
, Nanjing University, China; University of Nottingham, United Kingdom

Finite States Model Predictive Control (MPC) has been recently applied to several converters topologies for the many advantages it can provide such as fast dynamics, multi-target control capabilities, easy implementation on digital control board and capability of including constraints in the control law. However, its variable switching frequency and lower steady state waveform quality, with respect to standard control plus modulator systems, represents a limitation to its applicability. Modulated Model Predictive Control (M2PC) combines all the advantages of the simple concept of MPC together with the fixed switching frequency characteristic of PWM algorithms. In particular this work focuses on the Indirect Matrix Converter (IMC), where the tight coupling between rectifier stage and inverter stage has to be taken into account in the M2PC design. This paper proposes an M2PC solution, suitable for IMC, with an optimal switching pattern to emulate the desired waveform quality features of Space Vector Modulation (SVM). In the optimal pattern, the switching sequences of the rectifier stage and inverter stage are rearranged in order to always achieve zero-current switching on the rectifier stage, thus simplifying its commutation strategy. In addition, the optimal pattern enables M2PC to produce sinusoidal source current, sinusoidal output current and maintain all desirable characteristics of MPC.

**10:35AM***Improved Steady State Behavior of Finite Control Set Model Predictive Control applied to a Flying Capacitor Converter [#227]*  
Margarita Norambuena, Pablo Lezana and Jose Rodriguez   
, Technishe Universitaet Berlin, Germany; Universidad Tecnica Federico Santa Maria, Chile; Universidad Andres Bellos, Chile

Finite Control Set Model Predictive Control (FCS-MPC) allows to deal with non- linearities of the system and obtain a fast dynamic response. Therefore FCS- MPC is a good alternative to govern complex power converters or when fast transient operation is required. The main drawback of FCS-MPC is the performance obtained during the steady state, the main reason resides in the poor temporal resolution of FCS-MPC and the mismatch of the model parameters. This paper presents a new way to implement FCS-MPC to correct the mismatch in the model parameters and achieve a better performance in steady state. This is achieved through the incorporation of the past error in the action of the control, adding an additional term in the cost function with a variable weighting factor.

Reluctance Machines

Tuesday, September 20, 8:30AM-11:00AM, Room: 102B, Chair: Akira Chiba, Yun Wei Li

**8:30AM***A new application and experimental validation of moulding technology for Ferrite Magnet Assisted Synchronous Reluctance Machine [#872]*  
Qian Wu, Kaiyuan Lu, Keld Folsach Rasmussen and Peter Omand Rasmussen   
, Aalborg University, Denmark; Grundfos A/S, Denmark

This paper introduces a new application of moulding technology to the installation of ferrite magnet material into the rotor flux barriers of Ferrite Magnet Assisted Synchronous Reluctance Machine (FASynRM). The feasibility of this application with respect to manufacturing process and motor performance has been demonstrated. In comparison to the conventional ferrite magnet installation approach, moulding technology has obvious advantages of improved mechanical strength of the multi-flux-barrier rotor structure, simplified installation process, reduced processing cost and in the same time, allowing a high degree of flexibility in the rotor flux barrier shape design. A prototype is manufactured using the moulding technology, and the attractive features are verified by detailed experimental results.

**8:55AM***Magnetic Field Analytical Computation in Synchronous Reluctance Machines Considering the Iron Saturation [#634]*  
Hanafy Mahmoud, Nicola Chiodetto and Nicola Bianchi   
, Padova University, Italy

This paper deals with an analytical model of REL motor considering the stator slotting effect and the magnetic saturation in the stator and rotor iron paths. It joints the field distribution at the air-gap to a lumped-parameter magnetic network. As an example, 36-slot 4-pole machine is analyzed, considering three flux barriers per pole. Finite element analysis confirms the results achieved by means of the analytical model.

**9:20AM***Performance Comparison of Short Pitched and Full Pitched Switched Reluctance Machines for Off-Road Vehicle Applications [#1526]*  
Tausif Husain, Wasi Uddin and Yilmaz Sozer   
, University of Akron, United States

This paper presents a comprehensive comparison of switched reluctance machines (SRM) with short pitched and full pitched windings for the same machine geometry. A switched reluctance machine designed for off-road vehicles with short-pitched windings is rewound with full-pitched windings and the two winding structures are compared. The effect of number of turns on the torque speed characteristics is also investigated. The two different winding configurations were evaluated with unipolar excitation at the same bus voltage level of the driver. The machines are compared with respect to their electromagnetic behavior, operating range, torque per ampere, and efficiency. The comparison would better guide designers on what type of configuration would best suit to their applications. The comparison is conducted with the aid of Finite element analysis. An experimental 50 kW prototype for the off-road vehicle application is used for experimental validation.

**9:45AM***A Fault Tolerant Machine Drive based on Permanent Magnet Assisted Synchronous Reluctance Machine [#1563]*  
Bo Wang, Jiabin Wang, Antonio Griffo, Zhigang Sun and Ellis Chong   
, The University of Sheffield, United Kingdom; Rolls-Royce plc, United Kingdom

A fault tolerant machine drive based on permanent magnet (PM) assisted synchronous reluctance machine is proposed and investigated for safety critical applications. In order to achieve enhanced fault tolerant capability, the risk of the permanent magnet field that cannot be turned off under fault conditions is minimized without compromising the torque density and efficiency. This is achieved by employing a synchronous reluctance rotor topology with embedded permanent magnets. Three independent 3-phase windings are adopted and a segregated winding configuration is devised to ensure non-overlapping in the three 3-phase winding sets. Each 3-phase winding set is driven by a standard 3-phase inverter, which facilitates fast integration and cost reduction. The performance under various fault conditions has been evaluated by FE simulations. The results show that the proposed machine drive exhibits high performance as well as excellent fault tolerant capability under various faults, including open circuit, terminal short circuit, and inter-turn short circuit, etc.

**10:10AM***A General Approach for the Analysis and Comparison of Hybrid Synchronous Machines With Single-Axis or Bi-Axial Excitation [#1674]*  
Fabio Giulii Capponi, Gabriele Borocci, Ion Boldea, Giulio De Donato and Federico Caricchi   
, University of Roma "La Sapienza", Italy; Politeh. Univ. of Timisoara, Romania

Hybrid Excitation Synchronous Machines allow broad flux regulation, and therefore a very wide Constant Power Speed Range. Literature shows that it is possible to build them both with a Single Axis and with a Bi Axial excitation. This paper presents a unified approach for the analysis, comparison and performance prediction of the two structures. Finite element simulation and experimental tests are carried out on a Torus type Axial Flux prototype, which, having two rotors, one equipped with PM and one with WE, allows for an easy structure reconfiguration on the same machine.

**10:35AM***Flux Modulation Principles of DC-Biased Sinusoidal Current Vernier Reluctance Machines [#728]*  
Shaofeng Jia, Ronghai Qu, Dawei Li and Jian Li   
, Huazhong University of Science and Technology, China

DC-biased sinusoidal current vernier reluctance machines (DC-biased-VRMs) are with a doubly salient structure, and their phase currents contain an alternating current (AC) component and a direct current (DC) component. Hence, their main features are one set of concentrated windings compared with variable flux reluctance machines (VFRMs), low vibration and noise due to smooth current, compared with switched reluctance machines (SRMs), and robust rotor structure. Besides, its achievable high slot fill factor can improve the torque density further. However, the existing DC- biased VRMs, whose stator/rotor slots of 6/4 and 6/8 have high torque ripple. In this paper, based on the flux modulation principles, the torque production mechanism of DC-biased VRMs are analyzed and two slot combinations of 12/8 and 12/10 are proposed. Firstly, the machine topology and inverter main circuit is illustrated. Secondly, the stator armature pole pairs/rotor pole relationship and pole ratio is given. Furthermore, the inductance, optimal current configuration for maximum torque and lowest torque ripple are theoretically analyzed and by the finite element analysis (FEA). Finally, one prototype has been designed and under built, and the experimental results will be then given.

Materials and Manufacturing Issues of Electric Machines

Tuesday, September 20, 8:30AM-11:00AM, Room: 101A, Chair: Aldo Boglietti, Daniel Ludois

**8:30AM***Stator Lamination Geometry Influence on the Building Factor of Synchronous Reluctance Motor Cores [#665]*  
Andrea Cavagnino and Zbigniew Gmyrek   
, Politecnico di Torino, Italy; Lodz University of Technology, Poland

The study investigates the influence of the lamination geometry on the building factor of stator magnetic cores, quantifying by experiments the influence of the punching and the annealing process. The research and the experimental activity are focused on small fractional power synchronous reluctance motors, where the punching process effect is expected to be very impacting, not only for the stator iron losses increase, but also because the current magnetizing component is dominant in the total adsorbed current. However, the obtained results are particularly interesting for any fractional and low power electric machines, whose cores are built with punched or laser-cut laminations.

**8:55AM***Influence of PM Coating on PM Magnetization State Estimation Methods Based on Magnetoresistance Effect [#1589]*  
Daniel Fernandez, David Reigosa, Juan Manuel Guerrero, Zi-Qiang Zhu and Fernando Briz   
, University of Oviedo, Spain; University of Sheffield, United Kingdom

Variable flux PMSMs (VF-PMSMs) are gaining importance, especially in automotive applications. The use of such machines will require the development of methods to estimate the permanent magnet (PM) magnetization state. PM magnetization state estimation methods reported in literature include BEMF and high frequency signal injection. One advantage of high frequency signal injection methods is that they can operate over the whole speed range, with practically no interference with the regular operation of the machine. Magnetization estimation using high frequency injection relies on the variation of the d-axis high frequency inductance with the saturation produced by the magnets. Alternatively, the changes of the magnet electrical resistance due to the magnetoresistive effect can also be used for this purpose. These methods have been tested with different materials, including NdFeB, AlNiCo and SmCo magnets. NdFeB magnets are usually protected from oxidation using NiCuNi coating. However, NiCuNi also shows magnetoresistance effect, and can affect therefore the performance of the method when used with magnets having NiCuNi coating. This paper studies the effects of PM coating on the performance magnetization estate estimation by means of high frequency signal using the magnetoresistance effect. The analysis will include NdFeB, AlNiCo and SmCo magnets. 1

**9:20AM***Investigation of the Impact of Production Processes on Iron Losses of Laminated Stator Cores for Electric Machines [#341]*  
Marc Veigel, Alexandra Kraemer, Gisela Lanza and Martin Doppelbauer   
, Karlsruhe Institute of Technology, Germany

To further improve the power density of modern electric drive technologies many motor designers decide to increase the rotational speed of the motor up to several tens of thousands revolutions per minute. Along with these high frequencies of the fundamental wave of the flux density inside the laminated stator cores, the electromagnetic strain of the core and the importance of the iron losses are increasing. Due to this, the high amount of different mechanisms, responsible for these iron losses, need to be identified and associated to the appropriate production process. For this reason, a suitable and inline-capable electromagnetic measuring method is used to determine the iron losses for real motor stator core geometries and to separate the impact of different production steps. In this paper, the large number of manufacturing methods for stator cores is presented and the iron losses are assigned to the corresponding production step in an overall consideration. The cause of the measured losses are identified and described. The mentioned measuring adapter can also be used to monitor a specific assembly line with regard to separation and joining quality to represent an innovative and economic possibility of quality assurance.

**9:45AM***Influence of Manufacturing Tolerances on Cogging Torque in Interior Permanent Magnet Machines with Eccentric and Sinusoidal Rotor Contours [#64]*  
Xiao Ge and Z. Q. Zhu   
, University of Sheffield, United Kingdom

The rotor shaping methods are frequently used to reduce the cogging torque in interior permanent magnet (IPM) machines. This paper investigates the influence of manufacturing tolerances on cogging torque in IPM machines with eccentric and sinusoidal rotor contours. First, two 12-slot/8-pole IPM machine models are established and the fundamental performance under ideal conditions is presented. Then, based on the most sensitive distributions of non-ideal PMs and assembly tooth-bulges, additional cogging torque components are calculated respectively, together with a comparative study to identify the different sensitivities between the two rotor contour designs. For verification, the field spatial harmonics with and without considering the tolerances are further analyzed, followed by tests on the prototypes with and without amplified tolerances.

**10:10AM***A Practical Approach of Electromagnetic Analysis with the Effect of the Residual Strain due to Manufacturing Processes [#1383]*  
Hiroyuki Sano, Katsuyuki Narita, Eri Zeze, Takashi Yamada, Kazuki Ueta and Kan Akatsu   
, JSOL Corporation, Japan; Shibaura Institute of Technology, Japan

Toward reliable and advanced machine designs, a practical modeling method of degraded steel sheets due to manufacturing processes is proposed. The advantage of the proposed method is the fact that the required material data can be measured with the standard single sheet testing without special measurement equipment so that machine manufactures will be able to take into account of the degradation effects according to their manufacturing processes. In the proposed approach, an approximation function which represents spatial variation of the degradation for each BH and loss property is identified using measurement data of steel sheet strips which have different widths. The identified approximation functions provide the material properties for Finite Element Analysis. It is shown that FEA calculations using the proposed method reproduce well the measurement results of cut steel sheets.Obtained degradation function is also applied to a PMSM. We investigate how the degradation function influences on the performance of the machine such as the back EMF.

**10:35AM***Investigation of Emerging Magnetic Materials for Application in Axial-Flux PM Machines [#539]*  
Solmaz Kahourzade, Nesimi Ertugrul and Wen Soong   
, University of Adelaide, Australia

This paper investigates the performance of three magnetic materials: silicon iron, soft magnetic composite and amorphous magnetic material, as the stator of an axial-flux permanent-magnet machine. Three stators, one of each material, are built and tested with the same rotor. The losses of each of the machines are separated using a combination of 3D finite-element analysis and experimental testing under open-circuit and loaded conditions.

Induction Motor Drives

Tuesday, September 20, 8:30AM-11:00AM, Room: 101B, Chair: Sertac Bayhan, Di Pan

**8:30AM***A Compact Active Filter to Eliminate Common-Mode Voltage in a SiC-based Motor Drive [#1155]*  
Kellan Euerle, Kartik Iyer, Eric Severson, Rohit Baranwal, Saurabh Tewari and Ned Mohan   
, University of Minnesota, United States; MTS Systems Corporation, United States

This paper presents an active compensation device for common-mode (CM) voltage elimination in 3-phase space-vector pulse-width-modulated (SVPWM) inverters. The proposed device consists of a single-phase 2-level inverter (H-bridge) which supplies a compensating voltage to the inverter via a step- up common-mode transformer tied to all three phases at the output. The H- bridge active filter is supplied by a low voltage bus and switched several orders of magnitude faster than the inverter switching frequency. This device takes advantage of the direct knowledge of the switching pulses sent to the inverter to predict and generate the compensating voltage. A technique is employed to subtract the low frequency harmonics from the modulation of the H-bridge which allows for the size of the common-mode transformer to be reduced significantly. Small passive components are added to attenuate the active filter's PWM frequency content and thus produce an effective compensating voltage. This paper will review existing common-mode voltage compensation techniques and demonstrate that the proposed method is a logical choice for certain drive applications. Design considerations are included to provide understanding and guidance for implementation of the device, as well as MATLAB/Simulink simulation results to demonstrate the operation of the active compensation device. Final validation is presented through experimental results from a hardware prototype.

**8:55AM***Stator Inter-Turn Fault Detection for Seamless Fault-Tolerant Operation of Five-Phase Induction Motors [#1201]*  
Vivek M. Sundaram and Hamid A. Toliyat   
, Texas A and M University, United States

Multiphase motors have been shown to be advantageous in safety-critical and cost sensitive applications due to their ability to operate with open phases. However, for true fault-tolerant operation the motor drive must be able to detect an incipient fault and then transition to post fault operation. It is also desirable for the fault detection method to be non-intrusive and require minimal additional sensing. This paper investigates a low cost diagnostic method using DC voltage injection for monitoring and detection of stator inter-turn faults in five-phase induction motors. The proposed method is incorporated into the control loop and allows the motor to seamlessly transition from healthy to fault-tolerant operation after the fault is detected, with minimal modification to the control logic. It is validated with simulations as well as implemented on a microcontroller and tested on a five-phase induction motor with winding taps to emulate the inter-turn fault condition.

**9:20AM***Rotor Temperature Estimation in Doubly-Fed Induction Machines Using Rotating High Frequency Signal Injection [#474]*  
David Reigosa, Juan Manuel Guerrero and Fernando Briz   
, University of Oviedo, Spain

Thermal monitoring is a common feature in most of electric machine drives since thermal overloading is one of the most common causes of motor failures. Contact-type sensors are normally used to measure the stator temperature in electric machines. However, use of this type of sensor is not advisable in the rotor as it requires cabling to a rotating part or the use of a wireless transmission system. Consequently, measurement of the rotor temperature is not easy in practice and is not normally implemented in standard machines. An alternative to rotor temperature measurement is rotor temperature estimation. Up to date, only thermal models have been used for rotor temperature estimation in doubly-fed induction machines (DFIMs). This paper proposes rotor temperature estimation in DFIMs using high-frequency signal injection. The proposed method estimates the rotor temperature from the rotor high frequency resistance, which us a function of the rotor windings temperature. The method does not interfere with the normal operation of the drive and can be implemented in existing DFIM drives without requiring additional hardware

**9:45AM***Maximum Torque Output for Volts/Hz Controlled Induction Machines in Flux-weakening Region [#953]*  
Kai Wang, Kevin Lee, Wenxi Yao and Fayi Chen   
, Eaton corporation, China; Eaton Corporation, United States; Zhejiang University, China

For maximum torque control of induction machines (IM) in flux-weakening region, the following problems exist: 1. In Volts/Hz scalar control mode, a slow frequency ramp time cannot provide sufficient electromagnetic torque, whereas the excessive acceleration leads to overcurrent shutdown and system collapse; 2. In vector control mode, the under-estimated leakage inductance in field- weakening region can lead to system instability. To solve these problems, this paper presents a method based on both stability criteria and maximum torque capability for determining a proper frequency ramp-up profile. It retains the maximum torque output capacity on the basis of guaranteeing system stability in flux-weakening region. A proportional and integral (PI) controller is employed to adjust the frequency ramp time, which will be halted if the magnetizing current exceeds a predefined limit. Moreover, the proposed scheme has a larger tolerance of underestimated leakage inductance as compared with the vector controlled IM drives in flux-weakening region. Simulation studies on a 3hp (2.2kW) and a 20hp (15kW) have been conducted in both Volts/Hz and vector control modes. Experimental validation is presented on a 3hp (2.2kW) platform in Volts/Hz control mode. Both simulation and experimental results validate the analysis and show effectiveness of the proposed method in the defined scenarios.

**10:10AM***Performance Investigation of Selected Prediction Vectors Based FS-PTC for 3L-NPC Inverter Fed Motor Drive [#28]*  
Md Habibullah, Dylan Dah-Chuan Lu, Dan Xiao and Muhammed Fazlur Rahman   
, School of EIE, The University of Sydney, Australia; School of EET, University of New South Wales, Australia

Computational burden is a major hurdle for practical implementation of finite- state predictive torque control (FS-PTC) of motor drive fed by a multi-level inverter. One of the reasons of computational complexity is that all voltage vectors are evaluated for prediction and actuation. This paper proposes selected number of voltage vectors for the prediction and actuation, which are called prediction vectors in FS-PTC, and the performance is investigated for a three-level neutral-point clamped (3L-NPC) inverter fed motor drive. The number of prediction vectors is reduced based on the position of stator flux and the deviation in stator flux from its reference. Experimental results confirm that the computational burden is reduced significantly, while the dynamic performance in terms of torque and flux ripple, stator current total harmonic distortion (THD), neutral-point voltage, torque rise time, and average switching frequency is comparable to the all voltage vectors based FS- PTC.

**10:35AM***Inverter-fed Drive Stator Insulation Monitoring based on Reflection Phenomena Stimulated by Voltage Step Excitation [#895]*  
Clemens Zoeller, Markus Vogelsberger and Thomas Wolbank   
, TU Wien, Austria; Bombardier Transportation Austria, Austria

Reflected wave transient phenomena in voltages and currents of inverter-fed drives caused by voltage source inverters (VSI) operating with pulse width modulation (PWM) with high dv/dt rates are well known and analyzed in many studies. The reflection phenomena occurring at the machine terminals, resulting in high overvoltages are one reason for the stress and aging mechanism of AC machines insulation system. The motivation of this work arises out of the need for a continuous monitoring of the insulation health state for traction drives systems in order to ensure high reliability of the drive over many years of operation. With a voltage step initiated by a switching transition, the inverter elicits a response in the drive system. By using the information of the resulting transient effects, conclusions can be drawn on basis of the oscillation behavior which are indicative for a change in the insulation system. Investigations in this work show that an alteration in the shape of the system transients, in peak values as well as frequency components, correlates with a dielectric insulation capability of the machine winding insulation. Measurements on a small, low voltage, random wound, induction machine (5.5kW) and a medium voltage induction machine (1.4MW) with formwound coil based stator system are performed. Artificially induced insulation aging is realized by accelerated thermal aging to demonstrate the effect. Additionally, two different inverter types are used, with standard IGBT modules (dv/dt 2-4kV/us) and new SiC semiconductor inverter technology (dv/dt up to 20kV/us), to analyze the influence of the shape of the excitation voltage step.

PM and IPM Motor Drives I

Tuesday, September 20, 8:30AM-11:00AM, Room: 101CD, Chair: Nicola Bianchi, Prerit Pramod

**8:30AM***maximum torque per ampere control in stator flux linkage synchronous frame for DTC-based PMSM drives without using q-axis inductance [#286]*  
Atsushi Shinohara, Yukinori Inoue, Shigeo Morimoto and Masayuki Sanada   
, Osaka Prefecture University, Japan

When direct torque control (DTC) is applied to permanent magnet synchronous motor (PMSM) drives, the relationship between the torque and stator flux linkage is important for high-efficiency drives because DTC requires them as references. In the stator flux linkage synchronous frame (M-T frame), the torque is described by a simple equation using the T-axis current. However, the M-axis current is neglected in the equation. This paper derives the relationship between the M-axis current and the stator flux linkage and proposes a maximum torque per ampere (MTPA) control strategy for direct torque controlled PMSM drives using the above relationship. The proposed method does not require the q-axis inductance, which often varies due to the magnetic saturation. The simulation and experimental results verify that the MTPA condition can be obtained with the proposed method.

**8:55AM***A Novel Direct Torque Control Strategy for Interior Permanent Magnet Synchronous Motors Driven by a Three-level Simplified Neutral Point Clamped Inverter [#290]*  
Tung Ngo, Gilbert Foo, Craig Baguley, Deepu Mohan and Xinan Zhang   
, Auckland University of Technology, New Zealand; Nanyang Technological University, Singapore; University of New South Wales, Australia

Compared to the three-level neutral point clamped (3L-NPC) inverter, its simplified version, the 3L-SNPC, uses fewer switching devices to achieve a multi-level output. However, it offers fewer voltage vector selections, limiting its usefulness for motor drive applications. This issue is overcome through a proposed direct torque control (DTC) strategy utilizing the concept of virtual voltage vectors to increase the number of voltage vector selections available. In addition, a DTC based switching table employing at least one voltage vector within each sampling period is proposed to reduce the torque ripple. Further, the issue of neutral point capacitor voltage unbalance is addressed. The strategy is modelled for an Interior Permanent Magnet Synchronous Motor driven by a 3L-SNPC, and simulation results prove its feasibility. To the knowledge of the authors, the proposed strategy has not previously been reported.

**9:20AM***Fault Tolerant Capability of Deadbeat - Direct Torque and Flux Control for Three-Phase PMSM Drives [#335]*  
Mario Pulvirenti, Giuseppe Scarcella, Giacomo Scelba and Robert D. Lorenz   
, University of Catania, Italy; University of Wisconsin-Madison, United States

This paper investigates the performance of a three phase permanent magnet synchronous machine (PMSM) drive operating under a single fault, adopting a fault tolerant (FT) control, based on deadbeat - direct torque and flux control (DB-DTFC). DB-DTFC offers an independent regulation of the electromagnetic torque and the stator flux linkage by using a control law based on an inverse discrete time physical model. During fault conditions, the PMSM drive requires very limited hardware and software reconfigurations. The drive model equations result very similarly to those adopted for the healthy electric drive just by using a different matrix transformation set when the drive operates under a faulty condition. The proposed fault tolerant DB-DTFC ensures satisfactory faulty operations and drive stability, without increasing the computational efforts.

**9:45AM***Online MTPA Control for Salient-Pole PMSMs Using Square-Wave Current Injection [#569]*  
Yue Zhao   
, University of Arkansas, United States

The maximum torque per ampere (MTPA) control has been widely employed to improve the efficiency of the permanent-magnet synchronous machine (PMSM) drive systems. To achieve accurate online MTPA tracking, in this work, a high- frequency current injection based method is proposed. Compared to the lookup- table based MTPA control, the proposed method can significantly reduce the pre-tuning effort. Since a high-frequency square-wave signal is injected, compared to the existing sinusoidal signal injection based MTPA control, the proposed method can eliminate the bandpass filter, which is usually used to extract the derivative of torque with respect to the current control angle, such that the bandwidth of the MTPA controller can be increased. In this work, the proposed MTPA tracking can be implemented by using either virtual or real signal injection. In addition, the effect brought by magnetic saturation is analyzed in this work and the corresponding solutions are presented to mitigate this effect. The feasibility and effectiveness of proposed methods are verified by both simulation and experimental studies.

**10:10AM***Automatic MTPA Tracking in IPMSM Drives: Loop Dynamics, Design and Auto-Tuning [#1529]*  
Nicola Bedetti, Sandro Calligaro, Christian Olsen and Roberto Petrella   
, Gefran s.p.a., Italy; DPIA - University of Udine, Italy

In the control of Interior Permanent Magnet Synchronous Machines (IPMSMs), Maximum Torque Per Ampere (MTPA) based on motor parameters is a common approach to achieve high efficiency and torque density. Parametric uncertainty (e.g. due to identification errors, magnetic saturation or temperature variation) results in undesired deviation from the optimal operating trajectory. To solve this problem, MTPA tracking methods have been proposed, which exploit signal injection to search the minimum current point for a certain load torque, in a closed loop fashion. For one of these methods, [13], stability of the non linear dynamics was analyzed, and an upper bound for the convergence time was found, but no explicit method was proposed for the design of the tracking regulator. In this paper this last topic is addressed. By introducing some approximations, the linearized system is calculated and a loop transfer function obtained, which is invariant with the operating point. Thus, by means of a very simple design rule (i.e. suitable for auto tuning), the MTPA tracking regulator gains can be designed in order to obtain the desired bandwidth. The method has been studied analytically and in simulation, also considering the influence of noise and parametric uncertainties. Finally the technique has been implemented on the hardware of a commercial industrial drive, proving the effectiveness of the proposal.

**10:35AM***Reduction of Unbalanced Axial Magnetic Force in Post-fault Operation of a Novel Six-phase Double-stator Axial Flux PM Machine Using Model Predictive Control [#943]*  
Hanxiao Lu, Jian Li, Ronghai Qu, Linyuan Xiao and Donglin Ye   
, Huazhong University of Science and Technology, China

This paper investigated the post-fault operation of a novel six-phase double-stator axial flux permanent magnet machine with detached winding configuration, which was found to be superior to existing winding configuration in previous study. However, the unbalanced magnetic force problem still remains unsolved. In this paper, the axial force balancing control principle is proposed and a group of specific current waveforms are deduced. When applying these currents under post-fault condition, magnetic torque, axial magnetic force and rotor losses of the machine are calculated in finite element analysis. The results are compared with normal condition and commonly-used post-fault current waveforms. It is verified that this method reduced the unbalanced axial magnetic force immensely and the torque ripple was also kept at a low level. In order to achieve the proposed current waveform, finite control set model predictive control (FCS-MPC) is adopted. This paper proposed the post-fault model of dual three-phase permanent magnet machines and designed a cost function to track the desired current waveforms. The model of the machine is used to predict the future behavior of the controlled variables and the cost function decides the next step of the inverter by evaluating all the predictions. At last, it is verified by simulation results that the control strategy performs well in both dynamic and steady-state situations.

Wide Bandgap Applications: Comparative Studies

Tuesday, September 20, 8:30AM-11:00AM, Room: 202C, Chair: David Reusch, Robert Pilawa-Podgurski

**8:30AM***Comparative Evaluation of 15 kV SiC IGBT and 15 kV SiC MOSFET for 3- Phase Medium Voltage High Power Grid Connected Converter Applications [#1605]*  
Sachin Madhusoodhanan, Krishna Mainali, Awneesh Tripathi, Arun Kadavelugu, Kasunaidu Vechalapu, Dhaval Patel and Subhashish Bhattacharya   
, North Carolina State University, United States

The advent of high voltage (HV) wide band-gap power semiconductor devices has enabled the medium voltage (MV) grid tied operation of non-cascaded neutral point clamped (NPC) converters. This results in increased power density, efficiency as well as lesser control complexity. The multi-chip 15 kV/40 A SiC IGBT and 15 kV/20 A SiC MOSFET are two such devices which have gained attention for MV grid interface applications. Such converters based on these devices find application in active power filters, STATCOM or as active front end converters for solid state transformers. This paper presents an experimental comparative evaluation of these two SiC devices for 3-phase grid connected applications using a 3-level NPC converter as reference. The IGBTs are generally used for high power applications due to their lower conduction loss while MOSFETs are used for high frequency applications due to their lower switching loss. The thermal performance of these devices are compared based on device loss characteristics, device heat-run tests, 3-level pole heat-run tests, PLECS thermal simulation based loss comparison and MV experiments on developed hardware prototypes. The impact of switching frequency on the harmonic control of the grid connected converter is also discussed and suitable device is selected for better grid current THD.

**8:55AM***Comparison between SiC and GaN devices in 6.78 MHz 2.2 kW resonant inverters for wireless power transfer [#807]*  
Jungwon Choi, Daisuke Tsukiyama and Juan Rivas   
, Stanford University, United States; DAIHEN Advanced Component, Inc, Japan

This paper presents a performance comparison of two wide band gap (WBG) devices, a silicon carbide (SiC) MOSFET and an enhancement mode gallium nitride (eGaN) FET in a resonant inverter operating at 6.78 MHz for wireless power transfer (WPT) applications. While SiC MOSFETs provide high breakdown voltage and good thermal characteristics, eGaN FETs can reduce gate losses due to small gate resistance and input capacitance. In this work, we compare a 1200 V SiC MOSFET in a single-ended class Phi2 inverter to two 650 V eGaN FETs in a push-pull class Phi2 inverter. We designed and implemented a 6.78 MHz 2.2 kW single-ended class Phi2 inverter using a 1200 V customized SiC MOSFET with low-inductance package. In our experiments, the inverter has a 93% efficiency and 2.2 kW output power with input voltage of 440 V. We also implemented a push-pull class Phi2 inverter using a 650 V eGaN FET at 6.78 MHz. The push-pull class Phi2 inverter reduces the input current ripple because of interleaving operation. At 200 V input voltage, the push-pull inverter with two eGaN FETs provides output power of 2 kW with 96% efficiency. In order to reduce a volume and weight of the inverter, we implemented a class Phi2 inverter with 3D printed inductors.

**9:20AM***Comparison of GaN FET and Si MOSFET Based Vienna Rectifiers [#1390]*  
Yutong Zhu and Yehui Han   
, University of Wisconsin Madison, United States

As the technology on wide bandgap materials such as gallium-nitride (GaN) has advanced rapidly, commercial GaN power devices with satisfying performance are available now. It is widely-known that GaN-based switching devices have several advantages over traditional Si-based switching devices, such as lower ON-resistance, faster switching speed, better thermal conductivity, and smaller size. However, researchers have not yet fully explored and applied GaN devices in some of the important power conversion applications. In this paper, a popular three-phase three- level three-switch Vienna rectifier is designed with GaN FETs. The advantages and challenges of utilizing GaN FETs in Vienna rectifiers are discussed. The topology, control and simulation are carried out as well. To provide a comparative analysis of the GaN FET and Si MOSFET based Vienna rectifiers, two prototypes are built with each type of the power devices on a similar scale. Detailed comparative analysis discussions based on the experimental results, including size, power circuit efficiency and THD, are provided. It is concluded in this paper that GaN FETs and their drivers have smaller size and higher power density compared with Si MOSFETs and their drivers. The overall performance of the GaN FET and Si MOSFET based Vienna rectifiers are at the same level, although driving techniques of the GaN FET devices are not mature.

**9:45AM***Comparison of GaN and SiC Power Devices in Application to MW-scale Quasi-Z-Source Cascaded Multilevel Inverters [#835]*  
Haiyu Zhang, Baoming Ge, Yushan Liu, Bayhan Sertac, Robert S. Balog and Haitham Abu-Rub   
, Texas A and M University, United States; Texas A and M University at Qatar, Qatar

Wide bandgap (WBG)semiconductors including gallium nitride (GaN) and silicon carbide (SiC)offer significant performance improvement compared with conventional silicon power devices. The quasi-Z-source cascaded multilevel inverter (qZS-CMI)provides many advantages over the conventional CMI while applied in photovoltaic (PV) systems. In this paper, two solutions are proposed and compared for the design goal of a high efficiency and low cost qZS-CMI based 1 MW/11 kV PV system. The first solution is based on 650 V GaN enhancement mode high-electron-mobility transistors (E-HEMT) and 650 V SiC Schottky diodes. The second solution uses 1200 V SiC power modules and 1200 V SiC Schottky diodes. The power losses and costs of the two candidate designs are compared in details. It is concluded that the first solution shows lower power losses and costs per quasi-Z-source inverter (qZSI) module. However, due to low voltage rating of GaN E-HEMTs, more qZSI modules are needed to achieve the overall 11kV inverter rating. Therefore, the second solution shows lower total power loss and cost in the medium-voltage, MW-scale qZS-CMI PV system.

**10:10AM***Comparison of deadtime effects on the performance of dc-dc converters with GaN FETs and Silicon MOSFETs [#231]*  
John Glaser and David Reusch   
, Efficient Power Conversion, United States

Switching loss is an important and often the dominant source of converter losses. While soft-switching can greatly reduce the impact of switching loss, hard-switching is often preferred due to the simplicity of design, control, and implementation. Wide bandgap (WBG) semiconductors such as gallium nitride (GaN) and silicon carbide (SiC) have greatly reduced switching losses due to faster transition speeds, reduced output capacitance and reduction or elimination of reverse recovery. However, the high reverse voltage drop during deadtime and resulting conduction loss of WBG devices has led to the belief that deadtime management is more important than for silicon MOSFETs. This paper quantifies the effects of output capacitance, reverse recovery, and deadtime. It highlights the relationship between deadtime and reverse recovery, and provides experimental results showing that silicon MOSFETs can show far greater losses than GaN as a result of poor deadtime management.

**10:35AM***Characterization and Comparison of Latest Generation 900-V and 1.2-kV SiC MOSFETs [#1581]*  
Alinaghi Marzoughi, Rolando Burgos and Dushan Boroyevich   
, CPES - Virginia Tech, United States

This paper performs static and dynamic performance characterization of latest generation 900-V and 1.2-kV discrete Silicon Carbide (SiC) MOSFETs from four well-known manufacturers: CREE, ROHM, General Electric (GE) and Sumitomo Electric Industries (SEI). The static characterization performed includes acquisition of output characteristics, transfer characteristics, specific on- state resistances, threshold voltages and junction capacitances of the devices under test (DUTs). The static characterizations are done from 25C up to 150C to investigate variation of parameters versus temperature. At the other hand and for dynamic characterization, following a double-pulse tester design the tests are done at four different temperatures on all devices: 25C, 100C, 150C and 200C. In dynamic test, recommended gate voltages are applied to all devices and the switching speeds are matched. The switching losses are computed from double-pulse test (DPT) results.

Gate Drive Techniques I

Tuesday, September 20, 8:30AM-11:00AM, Room: 102A, Chair: Prasad Enjeti, Daniel Costinett

**8:30AM***High Speed Optical Gate Driver for Wide Band Gap Power Transistors [#435]*  
Davy Colin and Nicolas Rouger   
, Grenoble Electrical Engineering Laboratory, France

This paper presents the design of a CMOS gate driver fabricated in 0.18 um technology. Optical receivers are integrated to provide the highest dV/dt immunity. A configurable buffer with 7A current capability is also integrated. Two solutions of optical receivers and gate signal transfer are introduced. In both cases a particular attention is addressed to the delays and delay mismatches for high frequency converter applications. The effects of temperature, supply voltage and input photocurrent amplitude are investigated. Delay mismatches <5ns are expected. This CMOS gate driver has shown by experiments high switching frequency operation (typically 1.5 MHz) with low overall propagation delays (<25ns).

**8:55AM***Reduction of oscillations in a GaN bridge leg using active gate driving with sub-ns resolution, arbitrary gate-impedance patterns [#667]*  
Harry C. P. Dymond, Dawei Liu, Jianjing Wang, Jeremy J. O. Dalton, Neville McNeill, Dinesh Pamunuwa, Simon J. Hollis and Bernard H. Stark   
, University of Bristol, United Kingdom

Active gate driving provides an opportunity to reduce EMI in power electronic circuits. Whilst it has been demonstrated for MOS-gated silicon power semiconductor devices, reported advanced gate driving in wide-bandgap devices has been limited to a single impedance change during the device switching transitions. For the first time, this paper shows multi-point gate signal profiling at the sub-ns resolution required for GaN devices. A high-speed, programmable active gate driver is implemented with an integrated high-speed memory and output stage to realise arbitrary gate pull-up and pulldown resistance profiles. The nominal resistance range is 120 mO to 64 O, and the timing resolution of impedance changes is 150 ps. This driver is used in a 1 MHz GaN bridge leg that represents a synchronous buck converter. It is demonstrated that the gate voltage profile can be manipulated aggressively in nanosecond scale. It is observed that by profiling the first 5 ns of the control deviceâ€™s gate voltage transient, a reduction in switch-node voltage oscillations is observed, resulting in an 8-16 dB reduction in spectral power between 400 MHz and 1.8 GHz. This occurs without an increase in switching loss. A small increase in spectral power is seen below 320 MHz. As a baseline for comparison, the GaN bridge leg is operated with a fixed gate drive strength. It is concluded that p-type gate GaN HFETs are actively controllable, and that EMI can be reduced without increasing switching loss.

**9:20AM***Design Considerations and Comparison of High-speed Gate Drivers for Si IGBT and SiC MOSFET Modules [#1220]*  
Shan Yin, King Jet Tseng, Pengfei Tu, Rejeki Simanjorang and Amit K. Gupta   
, Nanyang Technological University, Singapore; Rolls-Royce Singapore Pte. Ltd., Singapore

The high switching frequency (> 20 kHz) of SiC MOSFET module makes it as an attractive alternative of Si IGBT module for high power density applications. Since SiC MOSFET and Si IGBT have the similar MOS-gated structure, it is normally regarded that the gate driver of SiC MOSFET can directly inherit from that of Si IGBT. However, considering the different device physics properties, some special design considerations need to be taken. In addition, the higher dv=dt and di=dt in SiC MOSFET module leads to more serious EMI issues, which will comprise the switching speed in return. In this work, the high-speed gate drivers for Si IGBT and SiC MOSFET modules with similar ratings are designed and optimized. Based on the experiment of switching characterization, the considerations of gate driver design to migrate from Si IGBT module to SiC MOSFET module are presented. And the EMI issue is the major challenge in the gate driver design for SiC MOSFET module.

**9:45AM***Active Gate Driving Technique for a 1200 V SiC MOSFET to Minimize Detrimental Effects of Parasitic Inductance in the Converter Layout [#1432]*  
Parthasarathy Nayak and Kamalesh Hatua   
, Indian Institute of Technology Madras, India

A 1200 V SiC MOSFET switches at much faster rate compared to a Si IGBT. As a consequence, SiC MOSFET experiences comparatively more ringing in device voltage and current due to the presence of parasitic inductance in the converter layout. Therefore, it is not straightforward to retrofit SiC MOSFETs in the converter layout of IGBTs where parasitic inductance appears in the range of 100 nH to 300 nH. This paper proposes an active gate driving technique for SiC MOSFET to improve overall switching performance in the presence of parasitic inductance. The proposed driver allows SiC MOSFET to switch almost at its normal speed with relatively large amount of parasitic inductance in the layout (100 nH to 300 nH). The device voltage and current stresses are also controlled. The developed active gate driver is tested in a double pulse test bed. The performance of the active gate driver is also tested in a 10 kVA two level inverter driving an induction motor load.

**10:10AM***Comprehensive Evaluation of Gate Boost Driver for SiC-MOSFETs [#122]*  
Koji Yamaguchi and Yukihiko Sato   
, IHI Corporation, Japan; Chiba University, Japan

This paper presents fast, low loss, and low noise gate driver for Silicon- Carbide (SiC) MOSFETs. We proposed gate boost circuit to reduce switching losses and switching delay time without increasing switching noise. The proposed gate driver makes it possible to improve converters efficiency or enhance power density of converters. SiC power devices have attracted huge interest as next generation power devices. Normally, switching performances of power devices have trade-off between switching losses and switching noise. SiC- MOSFETs are expected to be able to switch faster than Silicon IGBTs, but faster switching might cause switching noise problem such as electromagnetic interferences (EMI). We proposed the gate boost circuit to improve switching performances of SiC-MOSFETs, and also confirmed that the proposed gate driver reduce switching losses and delay time with experimental results.

**10:35AM***Gate Driver for the Active Thermal Control of a DCDC GaN based Converter [#1028]*  
Pramod Kumar Prasobhu, Giampaolo Buticchi, Stephan Brueske and Marco Liserre   
, Kiel University, Germany

Wide-Band-Gap power semiconductors based on SiC and GaN offer some significant advantages compared to Si-devices, in particular higher switching speed and higher operating temperature. These features offer potentially increased power density, which makes the temperature management critical especially for the PCB and components to which the GaN is connected. In this paper, an active gate driver with active thermal control is implemented and can be used to alter the losses of a DC/DC buck converter based on GaN transistors, with the aim of reducing the thermal cycling thus improving the converter's lifetime.

Wireless Power Transfer II

Tuesday, September 20, 8:30AM-11:00AM, Room: 202B, Chair: Khurram Afridi, Huai Wang

**8:30AM***A Mistuning-Tolerant and Controllable Power Supply for Roadway Wireless Power Systems [#593]*  
Abhilash Kamineni, Grant A. Covic and John T. Boys   
, The University of Auckland, New Zealand

Inductive Power Transfer power supplies for electric vehicles (EV) charging in dynamic applications need to tolerate large variations in coupling and tuning with varying loads. This paper investigates the use of a buck converter to regulate the input voltage to a fixed frequency unidirectional switch push-pull converter to meet the requirements of dynamic charging. The presented circuit is optimised to remove some of the additional components introduced. A mathematical model is presented which shows the circuit is capable of operating while extremely mistuned in both the inductive and capacitive regions while maintaining low THD. A controller design is also presented allowing constant primary current operation, safe start up and operation under no load conditions. The results from a 1 kW prototype tolerating a 34% change in primary inductance is also presented.

**8:55AM***Power Converter with Novel Transformer Structure for Wireless Power Transfer Using a DD2Q Power Receiver Coil Set [#878]*  
Guangjie Ke, Qianhong Chen, Wei Gao, Siu-Chung Wong and Chi.K. Tse   
, Nanjing University of Aero. and Astro., China; Hong Kong Polytechnic University, Hong Kong

In an Inductive Power Transfer (IPT) system, the magnetic design of the primary and secondary pads is an important factor that determines the power transfer capability. This paper proposes a DD2Q power receiver coil set, a novel three coil magnetic pad that comprises a classical DD winding and two additional quadrature windings placed at the secondary side (referred to as 2Q). The DD2Q coil set achieves tolerance to larger lateral displacements and rotational displacements than conventional DD pads. A 100 W contactless energy transmission system using the proposed transformer is tested.

**9:20AM***A Wireless Power Transfer System with a Double Current Rectifier for EVs [#1236]*  
Toshiyuki Fujita, Tomio Yasuda and Hirofumi Akagi   
, Technova.inc, Japan; Tokyo Institute of Technology, Japan

The secondary coil installed on an EV is required to be small in size, light in weight, and efficient in power transfer, as well as tolerant in lateral misalignment with a large air gap. Also, a wireless power transfer system needs high power transfer. Both downsizing and high power transfer bring a thermal problem the secondary coil. This paper proposes a WPT system combining the so-called "series and series" connected resonant capacitors with a double-current rectifier to achieve a secondary coil current reduction that is an essential matter of the problem. The proposed WPT system employs solenoid coils that are superior to circular coils in terms of misalignment and flux-distribution performance. The secondary WPT coil rated at 18 A is designed, constructed, and tested to verify the principles of operation. The system efficiency is 90.0% at nominal air gap 135 mm without misalignment in output power 7 kW.

**9:45AM***Hybrid Control of Inductive Power Transfer Charger for Electric Vehicles using LCCL-S Resonant Network in Limited Operating Frequency Range [#306]*  
Jongeun Byeon, Minhyuck Kang, Minkook Kim, Dong-Myoung Joo and Byoung Kuk Lee   
, Sungkyunkwan University, Korea (South)

In this paper, a hybrid control of IPT system is proposed in limited operating frequency range according to coupling coefficients. The coupling coefficient k and self-inductance of pad vary according to misalignment and vertical distance condition in inductive power transfer (IPT) system. Those variation cause change of output voltage and zero phase angle (ZPA) frequency. Proposed method enables the system to operate in zero voltage switching (ZVS) region close to ZPA frequency for low VA rating. Moreover, the excessive output voltage caused by k variation is also controlled by phase-shift control considering the voltage rating of power semiconductor. However the operable frequency of IPT system is restricted in standard of society of automotive engineers. Thus, phase-shift angle beta should be calculated for ZVS operation under limited frequency condition because the frequency range of ZVS operation is reduced depending on the increase of beta. The frequency range to operate system in ZVS region nearby ZPA frequency is deduced from beta according to the coupling coefficient. Considering the limited frequency condition, the coupling coefficient range to apply the hybrid control is derived. The informative simulation and experimental results with a 3.3 kW IPT prototype are provided to verify the numerical analysis.

**10:10AM***Research on Seamless Transfer from CC to CV Modes for IPT EV Charging System Based on Double-sided LCC Compensation Network [#597]*  
Lu Jiang-Hua, Zhu Guo-rong, Lin Peng, Li Xiao-Kun, Li Wen-jing, Wong Siu-Chung and Jiang Jing   
, Wuhan University of Technology, China; Hong Kong Polytechnic University, Hong Kong; University of Western Ontario, Canada

In this paper, based on a double-sided LCC compensation network, the leakage inductance equivalent model of the loosely coupled transformer (LCT) is built and the constant current (CC) output with load independent is analyzed in an inductive power transfer (IPT) system. This paper proposes four resonance conditions for achieving constant voltage (CV) output in various load conditions for the compensation network. The Zero Voltage Switching (ZVS) operation for the primary side H-bridge converter can be achieved in CC mode and CV mode to minimize the switching loss. A seamless transfer control strategy is also investigated to realize transmission from CC mode to CV mode for IPT EV (electric vehicle) charging system. An IPT EV system with 3.3 kW transmission power is built. The theoretical analyses are confirmed by simulation and experiment results.

**10:35AM***Closed-Loop Control Design for WPT System Using Power and Data Frequency Division Multiplexing Technique [#173]*  
Zhongnan Qian, Ruichi Wang, Zhikun Wang, Jin Du, Jiande Wu and Xiangning He   
, Zhejiang University, China

For wireless power transfer (WPT) system, close-loop control fed from pick-up side is an important issue, in which a communication link is needed. Power and data frequency division multiplexing (FDM) transfer technique is attractive because it embeds communication into power transfer and uses the same coreless coils. By employing this method, a simplified closed-loop control method for WPT system is proposed in this paper. Compared to conventional closed-loop WPT systems, the proposed design eliminates extra communication channels and enhances the reliability of feedback. Moreover, the phase-shifted control model of the FDM based WPT system is derived, and it provides guideline for the controller design. Based on the analysis, both simulation and experimental results of a 100-W prototype are presented to verify the effectiveness of feedback communication and power transfer.

Tuesday, September 20, 11:00AM-12:30PM

Poster Session: Renewable and Sustainable Energy Applications

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Euzeli Santos Jr., Rajendra Prasad Kandula

**P1901***Power Balance Control and Circulating Current Suppression for MMC based EV Integration System Considering Users Requirement [#914]*  
Meiqin Mao, Tinghuan Tao, Yong Ding, Liuchen Chang and Nikos Hatziargyriou   
, Hefei University of Technology, China; University of New Brunswick, Canada; National Technical University of Athens, Greece

A modular multilevel converter MMC is a possible solution to integrate EV fleet into grid by embedding EVs into the DC link of each sub module of MMC. The charging discharging power differential control strategy considering EV users requirements in the same arm has been proposed in the previous work. However, it is also important that the balance among the power of three phase-units should be met up with meanwhile circulation current should be controlled to ensure the system operation stably. This paper proposes the control strategy of balancing power among three phase units for MMC Based EV fleet integrated into smart grid based on virtual SOC concept to realize the control objectives considering both EV users requirements and utility demands. In addition, a circulation current suppressor is designed for contributing to the power balance control. Detailed system structure and control scheme are presented and a MMC based EV integration system model is established in Matlab Simulink to verify that the power of three phase-units can be controlled differentially considering both EV users requirements and utility demands without affecting the output powers and currents waveforms of the system and the circulation current can be restrained

**P1902***Optimal Sizing of Energy Storage for PV Power Ramp Rate Regulation [#1438]*  
Qian Zhao, Kunna Wu and Ashwin M Khambadkone   
, Experimental Power Grid Centre, Singapore

With increasing PV power penetration in the modern power grid, a cost-effective solution to address PV intermittency becomes more and more compelling. The ramp rate of PV power can reach 60\% of its rated capacity in just 30 seconds. Energy storage is a technically feasible solution to suppress the adverse impacts of injecting intermittent power output with such a high ramp rate into the grid, but its cost is very high. Therefore, to reduce the system cost of integrating PV and maximize the grid operation profit, optimal sizing of energy storage is necessary. In this paper, a method of optimizing energy storage size for controlling PV ramp rate is presented. The characteristics of PV ramp rate are first investigated. Based on the results, an energy dispatch model for controlling PV ramp rate with fast response energy storage is developed. The optimal size of energy storage which minimizes system operation cost to accommodate high PV penetration is subsequently determined.

**P1903***Model-Based Adaptive Control of a Hydraulic Wind Power System [#775]*  
Masoud Vaezi and Afshin Izadian   
, Purdue School of Engineering and Technology, United States

In this paper a multiple model adaptive control (MMAC) strategy is used to mitigate the undesired effect of output power fluctuations in hydraulic wind power systems. This control structure is based on linear Kalman filters, probability block and PID controllers and aims to regulate the speed of generation unit. Nonlinearities and disturbances such as wind speed and valve position make the system work over a wide range of operating point which degrades the performance of the control loop. MMAC as an approach for these types of systems implemented and simulated to consider the control performance over the whole operating regimes.

**P1904***Sensorless speed control of a small wind turbine using the rectifier voltage ripple [#1004]*  
Juan Manuel Guerrero, Carlos Lumbreras, David Reigosa, Cristian Blanco and Fernando Briz   
, University of Oviedo, Spain; AST Ingenieria, Spain; Universidad de Oviedo, Spain

Grid-tied small wind turbines based on permanent magnet generators are usually operated using a basic converter topology based on a passive rectifier, a boost converter, and an H-bridge inverter. The rotor speed signal is rarely obtained from speed or position sensors in this kind of systems. Model-based estimators are rather used for this purpose relying on electrical magnitudes. Despite its complexity all models show inaccuracy under machine parameter change mainly due to temperature. A speed sensorless method is proposed in this paper based on the measurement of the rectifier voltage ripple. This method is insensitive to machine parameter change. The method will bring a significative improvement in the dynamic response of the small wind turbine system under unrated parameter operation. The proposed method is extended to detect the temperature of the electrical generator. Simulations will corroborate the validity of the proposed method.

**P1905***Maximum Power Point Tracking (MPPT) of Sensorless PMSG Wind Power System [#1335]*  
Yu Zou and Jiangbiao He   
, Saginaw Valley State University, United States; GE Global Research, United States

This paper investigates the modeling, simulation and implementation of sensorless maximum power point tracking (MPPT) of permanent magnet synchronous generator (PMSG) wind power system. A comprehensive portfolio of control schemes are discussed and verified by simulations and experiments. Both simulation and experimental results demonstrate a robust sensorless MPPT operation in the customized PMSG wind power system.

**P1906***Current/Voltage Sensor Fault Detection and Isolation in Wind Energy Conversion Systems Based on Power Balance [#1133]*  
Haibo Li, Liyan Qu, Wei Qiao and Chun Wei   
, University of Nebraska-Lincoln, United States

This paper proposes a novel current/voltage sensor fault detection and isolation (FDI) method for wind energy conversion systems (WECSs) based on the power balance principle. The proposed method uses the sensor-measured signals to calculate the imbalanced power in the power converters of a WECS, which is then used as the indicator for sensor fault detection. The fault isolation process is started when a fault is detected and is achieved by generating and comparing the residuals between the estimated and measured signals, where the residuals are generated by a trigonometric function-based estimation algorithm. The proposed method does not require additional hardware or the information of generator parameters, is capable of detecting and isolating both machine-side and grid- side current/voltage sensor faults, and is not influenced by other types of faults in WECSs or power grids. The effectiveness of the proposed method is confirmed by simulation results in MATLAB/Simulink and experimental results for a 2.4-kW permanent-magnet synchronous generator-based WECS.

**P1907***Quasi-Z-Source-Based Multilevel Inverter for Single-Phase Photo Voltaic Applications [#1217]*  
Aida Gorgani, Malik Elbuluk, Yilmaz Sozer and Haitham Abu-Rub   
, The University of Akron, United States; Texas A and M University at Qatar, Qatar

The use of multilevel inverters in Photovoltaic (PV) applications have attracted major attentions in both industry and academic research. This paper presents a PV system based on a single-phase Quasi-Z-Source (QZS) multilevel inverter with a great reduction in number of switches. The introduced inverter is based on a Multilevel DC link (MLDCL) structure and an H-bridge inverter. The MLDCL consists of cascaded half-bridge units with each unit having a PV cell and two switches as the main components. To regulate the PV voltage, a QZS network is considered in each unit in order to reach the desired level of voltage and the system would be able to perform in a wider range of PV output voltage in a more reliable and efficient system. A detailed analysis is applied to 180 W single phase stand-alone PV system with three cascaded half-bridge QZS networks and a 60 Hz H-bridge. Each QZS module in the proposed structure has the advantage of having an independent control scheme, using which each unit can effectively achieve the distributed maximum power point (MPP). The system is simulated to verify the proposed concept and theoretical analysis using Matlab/Simulink. The feasibility of the proposed topology is also confirmed through the experiment on a 60 W system.

**P1908***Dual Buck Based Power Decoupling Circuit for Single Phase Inverter/Rectifier [#840]*  
Xiao Li, Shunlong Xiao, Haiyu Zhang, Robert S. Balog and Baoming Ge   
, Texas A and M University, United States

Single phase rectifiers and inverters are inherently subject to double-line frequency ripple power, at both the ac and dc sides, which has adverse effects on the overall system performance. Normally a bulky capacitor is placed at the dc side of the circuit to prevent this ripple power ripple from reaching the dc source. This approach results in low power density and reliability issues. As a result, active power decoupling methods have been proposed such that the total capacitance required can be orders of magnitude smaller. This paper proposed a new power decoupling circuit, which is composed of two separate buck converters operating in each half cycle and two split dc-link capacitors. The dc link capacitors can be used to store ripple power while supporting transient power to the main output. The capacitance needed is reduced largely by allowing high voltage fluctuation on capacitors, while the dc link voltage can be controlled with small fluctuation. The dc link capacitors can be fully charged and discharged with full energy utilization. The added power decoupling module does not need dead time, and totally eliminates the shoot through concerns, which could enhance the system reliability. Another advantage of the proposed power decoupling method is that its control is independent with that of the main power stage. Modulation and control strategy are proposed for the power decoupling circuit. The operating principles together with parameters design are discussed in detail. Both simulation and experimental results prove the effectiveness of this method.

Poster Session: Smart Grid & Utility Applications

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Johan Enslin, Euzeli Santos Jr.

**P2101***Design and Development of a True Decentralized Control Architecture for Microgrid [#1126]*  
Abedalsalam Bani-Ahmed, Adel Nasiri and Hosseini Hossein   
, UW-Milwaukee, United States

Emerging smart grid concept compels microgrids to adopt decentralized methods.Centralized methods of operation are more susceptible to failure due to single point of failure held by the single controller. Decentralized microgrid control architecture is proposed, improving system reliability and avoiding control command transmission over the network. Delays in communications are unpredictable, uncertainty of data exchange delays leads to inaccurate modeling. As a solution, Hardware-in-The-Loop platform is developed using real physical communication links and network components, and applying the concept of decentralization dynamically over a network of real-time controllers. The proposed system insures reliable data exchange between controllers and microgrid components. Case study is adopted for testing purposes. Results proves the robustness of the architecture as long as the properties of a true decentralized system is maintained.

**P2102***Modeling and Control of a Synchronous Generator in an AC Microgrid Environment [#1127]*  
Luke Weber, David Hyypio, William Dittman and Adel Nasiri   
, University of Wisconsin Milwaukee, United States; Regal Beloit Marathon, United States

An AC microgrid system model is created to assess transient and steady state stability during periods of separation from the grid. A secondary control is constructed to dispatch energy sources according to user selected setpoints and participation factors. Two sources, an energy storage device and synchronous generator, are controlled to share active and reactive load burdens. A system load models the difference between solar and wind powered generation and load. First order differential equations are written to describe the system, and implemented in Simulink. The model components carry a high level of detail to capture all relevant modes. Systems include an eight state salient pole synchronous machine, AC8B regulator, prime mover, equivalent PI cable, RL microgrid load, ideal battery and basic inverter model, and a detailed LCL filter at the inverter output. A detailed model of the inverter primary control is included, and a secondary level control which distributes the power error according to user defined participation factors is proposed.

**P2103***State Estimation of Power Systems with Interphase Power Controllers Using the WLS Algorithm [#109]*  
Mohammad Amin Chitsazan and Andrzej M Trzynadlowski   
, University Of Nevada, Reno, United States

Traditional state estimation methods are not well suited for power systems with FACTS devices. A novel approach to state estimation of systems with interphase power controllers (IPC) is proposed. The extension of the conventional model of the system necessitates the use of constraints accounting for limits associated with the IPC operation and ratings. Results of tests on the IEEE 14 bus system using the weighted least-square method, have confirmed validity of the proposed approach.

**P2104***A Novel T-Type Half-Bridge Cell for Modular Multilevel Converter with DC Fault Blocking Capability [#368]*  
Fangzhou Zhao, Guochun Xiao, Daoshu Yang, Min Liu, Xiaoli Han and Baojin Liu   
, Xi an jiaotong university, China

The Modular Multilevel Converter (MMC) is very suitable for high-power applications such as High-Voltage Direct Current (HVDC) transmission system. However, the DC fault vulnerability seriously constrains the conventional Half-Bridge based submodule (HBSM) of MMC, while the Full-Bridge based SM (FBSM) and Clamp Double based SM (CDSM) with DC fault blocking capability greatly increase the costs. This paper presents a novel T- Type Half-Bridge based SM (T2HBSM) topology that is capable of blocking DC fault current and separating the AC grid from the DC fault point instantly, and it can rebuild the DC link voltage to get the MMC-HVDC back to normal immediately after the fault is clear. More significantly, the proposed T2HBSM topology saves one diode and utilizes the same number of switches in comparison with the CDSM. The simulation results in PSCAD/EMTDC demonstrate the feasibility of the proposed T2HBSM topology.

**P2105***A Distributed Control Method for Power Module Voltage Balancing of Modular Multilevel Converters [#376]*  
YongJie Luo, YaoHua Li, ZiXin Li and Ping Wang   
, StateGridSiChuanElectricPowerResearchInstitute, China; Key Laboratory of Power Electronics and Electric, China

This paper focuses on the distributed control method of the power module (PM) capacitor voltage balancing in modular multilevel converters (MMCs). The large number of PMs imposes great computational challenge on the capacitor voltage balancing in MMC based high voltage direct current (HVDC) transmission system. In this paper, a distributed voltage balancing method is proposed to reduce the computational load of control strategy of MMCs with hundreds of PMs per arm. With this method, all PMs in one arm of MMC are grouped first. The PMs in each group is balanced independently by voltage sorting and arm current polarity. The sorting all the PM voltages in this arm is avoided. Meanwhile, a close-loop control strategy is also introduced to balance the average PM voltage of each group dynamically. This paper proposed a distributed capacitor voltage balancing method for MMCs. This method divided PMs in each arm of MMC into several groups, calculates the reference number of each group and adjusts the reference number through a close-loop control in real-time. The proposed method avoided sorting of all the PM capacitor voltages and reduced the load of computation, which improved the computational speed of the MMC control system. The effectiveness of the control scheme is demonstrated by computer simulation results on a 700 kV 1000 MW MMC based HVDC system.

**P2106***Control Method of Single-phase Inverter Based Grounding System in Distribution Networks [#602]*  
Wen Wang, Yan Lingjie, Xiangjun Zeng, Zhao Xin, Wei Baoze and Guerrero Josep M.   
, Changsha University of Science and Technology, China; Aalborg University, Denmark

The asymmetry of the inherent distributed capacitances causes the rise of neutral-to- ground voltage in ungrounded system or high resistance grounded system. Overvoltage may occur in resonant grounded system if Petersen coil is resonant with the distributed capacitances. Thus, the restraint of neutral-to-ground voltage is critical for the safety of distribution networks. An active grounding system based on single- phase inverter is proposed to achieve this objective. Relationship between output current of the system and neutral-to-ground voltage is derived to explain the principle of neutral-to-ground voltage compensation. Then, a current control method consisting of proportional resonant (PR) and proportional integral (PI) with capacitive current feedback is then proposed to guarantee sufficient output current accuracy and stability margin subjecting to large range of load change. The performance of the control method is presented in detail. Experimental results prove the effectiveness and novelty of the proposed grounding system and control method.

Poster Session: Transportation Electrification Applications

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Jin Wang, Yaosuo "Sonny" Xue

**P2301***A Novel Energy Balanced Variable Frequency Control for Input-Series-Output-Parallel Modular EV Fast Charging Stations [#57]*  
Qi Tian, Hua Bai, Huang Alex, Teng Hui and Lu Juncheng   
, North Carolina State University, United States; Kettering University, United States

At present time, the most common electrical vehicle (EV) chargers employ a two-stage design, i.e., a front-end AC/DC stage + an isolated DC/DC converter. In this paper, an isolated dual-active-bridge (DAB) based single- stage AC/DC converter was proposed, which has the power-factor-correction (PFC) and zero-voltage-switching (ZVS) functions over the full-load range. By reducing one power stage and eliminating the large DC link capacitor, a high efficiency and high power density are achieved. Such topology can be used as a modular building block to scale up to 50kW by serial connecting the input terminals and paralleling output terminals. A novel energy-balanced variable switching frequency control for such input-series-output-parallel (ISPO) modular designed is proposed. A single-phase d-q transformation is implemented to achieve zero steady-state error. Simulation analysis and experimental validation are presented.

**P2302***An Adaptive Charging Control Strategy For Ultracapacitor Light Rail Vehicles [#421]*  
Zhou Rong, Huang Zhiwu, Li Heng, Wu Zhihui and Peng Jun   
, Central South University, China

In this paper, an adaptive extremum seeking control strategy with sliding mode is develop to charge the ultracapacitor light rail vehicles. Compared with existing model-based charging algorithms, the proposed extremum seeking (ES) charging control strategy is model-free, which implies that it can handle the ageing effect of ultracapacitors well. Moreover, a sliding mode mechanism is embedded into the charging controller to suppress the disturbances introduced by sensors. Simulation and experiment results are presented to show the effectiveness of the proposed design.

**P2303***A High Power Density Drivetrain-Integrated Electric Vehicle Charger [#1443]*  
Usama Anwar, Hyeokjin Kim, Hua Chen, Robert Erickson, Dragan Maksimovic and Khurram Afridi   
, University of Colorado Boulder, United States

This paper presents a new architecture for an isolated level 2 on-board electric vehicle (EV) battery charger which is integrated with the EV's drivetrain dc-dc boost converter. The proposed charger leverages many of the existing stages of a highly efficient and power-dense composite- architecture-based drivetrain boost converter. This composite boost converter comprises a buck, a boost and a dc transformer (DCX) stage. In selecting the proposed charging architecture, four alternative approaches to drivetrain integration are identified, explored and compared quantitatively in terms of added weight and charging losses. Out of the considered approaches, the proposed charging architecture provides an effective tradeoff between additional weight and charging losses. This drivetrain- integrated charger adds only a bridgeless-boost-based power factor correction (PFC) ac-dc stage, plus an H-bridge and a single winding to the composite boost converter, to achieve high-power on-board charging functionality without substantial additional weight. A 6.6 kW prototype of the proposed charger has been designed and its PFC stage built and tested. The PFC stage uses a digital implementation of a current sensor-less control strategy and employs effective ways of mitigating zero crossing distortion. The proposed charger architecture reduces the additional weight required for the on-board charging functionality, while achieving greater than 97\% peak efficiency for the added charger module PFC stage.

**P2304***Railway Power Conditioner Based on Delta-connected Modular Multilevel Converter [#161]*  
Jiao Shang, NingYi Dai, BaoAn Wang and Hao Chen   
, Southeast University Chengxian College, China; University of Macau, Macau; Southeast University, China; Weihai Power supply company, China

Single-phase traction loads generate negative sequence currents, reactive current and harmonics to the power grid. Modular multilevel converter (MMC) is a better alternative to implement railway power conditioner (RPC), which is connected to 25 kV supply system. A MMC with delta configuration is fit for controlling negative-sequence current because circulating currents across delta- connected clusters provide extra flexibility in unbalance control. A RPC based on delta-connected MMC is developed. Steinmetz theory is used to calculate fundamental frequency phase reference current. Since the obtained fundamental frequency phase reference current always has a 90 degree phase difference with the line voltage, the dc voltage balancing of the MMC is easy to achieve. In addition, harmonic reference current among the three phases are balanced to reduce the total rating of the converter. The design and control of the RPC based on delta-connected MMC are validated by simulation results.

**P2305***Dynamic Study of Electromechanical Interaction in Marine Propulsion [#856]*  
Jishnu Kavil Kambrath, Aaron Alexander Ayu, Youyi Wang, Yong-Jin Yoon, Xiong Liu, Chandana Jayampathi Gajanayake and Amit Kumar Gupta   
, Rolls-Royce NTU Corporate Lab, Singapore; Nanyang Techonological University, Singapore; Rolls-Royce Singapore Pte. Ltd, Singapore

Electrical propulsion is gaining popularity in the marine industry, because of its good energy management and better dynamic performance. An azimuth thruster driven by an electric motor is a common configuration found in modern electric propulsion systems. In recent years failures relating to bevel gears and bearings in azimuth thruster drive train failures were reported in the marine industry. The failures are believed to be attributed to the ship operation in extreme sea state conditions, resulting in dynamic mismatch between the motor drive and the mechanical drive train systems. Hence, an analysis of the mechanical drive train system behaviour under different control modes will be an asset to the industry. The azimuth thruster is simplified as a generalised six mass system and the induction motor dynamics are both modelled in MATLAB Simulink; under extreme condition in the sea, i.e. propeller ventilation, there are torsional stresses between masses that can affect the life expectancy of drive line components.

**P2306***Model-based Control Design for a Battery/Ultracapacitor DC-DC Converter System [#1326]*  
Anantharaghavan Sridhar, Phil Kollmeyer and Thomas Jahns   
, University of Wisconsin-Madison, United States

For battery and ultracapacitor hybrid energy storage systems, the design and control of the DC-DC converter is an important stage of the system design process. The design approach for a model-based controller for a half-bridge DC-DC converter is presented with experimental results from a scaled test configuration. The contribution of this paper lies in presenting a well- behaved discrete-time system model, a controller tuning methodology, and an effective technique to address the nonlinear system response caused by discontinuous conduction. The results show that the controller bandwidth and command tracking that is achieved with the proposed techniques meet application requirements, and that reduced design effort is required for the presented tuning methodology, combined with helpful physical insights. The presented approach can also be generalized to other DC-DC converter systems.

**P2307***Sliding Model Control Based On Estimation Of Optimal Slip Ratio For Railway Wheel Slide Protection Using Extremum Seeking [#382]*  
Qing Peng, Jianfeng Liu, Zhiwu Huang, Weirong Liu and Heng Li   
, Central South University, China

It is very important for railway vehicles to have a good braking performance to avoid the phenomenon of idling and skidding, which can be implemented by looking for and keeping an optimal slip ratio. The optimal slip ratio is a value existing in the creep zone of functions between friction coefficient and slip ratio corresponding to the maximum adhesion. Controller based on the sliding mode control needs to be entered an reference slip ratio which can be used to find out the optimal control by the designer and can be tracked by actual slip ratio by the controller. Moreover, as an indispensable factor for calculating slip ratio, vehicle velocity is estimated by the proposed algorithm based on locomotive dynamic model. Then the optimal control ensures the actual slip ratio is equal to or close to the best reference slip ratio generated by extremum seeking algorithm dynamically. According to those functions, the optimal slip ratio changes dynamically once the pavement behavior changes. The simulation result demonstrates that compared with constant reference slip ratios, the proposed dynamical seeking algorithm for optimal reference slip ratio achieves the effect of real-time adjustment for braking torque, which prevents the brake torque from being too large or small and guarantees the braking performance.

**P2308***Evaluation of Negative-Sequence-Current Compensators for High-Speed Electric Railways [#503]*  
Antonios Antonopoulos and Jan Svensson   
, ABB Corporate Research, Sweden

This paper evaluates three alternative topologies for a static compensator (StatCom), suitable to eliminate the negative-sequence currents in a railway system. The compensator is placed in a transformer substation, which feeds two separate sections of the catenary. The major requirements of this converter is to: (i) symmetrize the railway load as seen from the high-voltage side, (ii) control the catenary voltage to a defined level, and (iii) compensate for the harmonics generated by the rolling stock. The topologies investigated here are: (a) a 2-level converter with a common dc-bus capacitor, (b) a delta-connected modular multilevel converter (MMC) based on full-bridge submodules, and (c) a double-star MMC based on half-bridge submodules. The evaluation is based on the minimum device-rating requirements of each converter that fulfill the application requirements in the steady-state. Simulation results are provided to support the conclusions of this evaluation.

Poster Session: Power Converter Topologies

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Pradeep S. Shenoy, Leon M Tolbert

**P2501***A ZVS Integrated Single-Input-Dual-Output DC/DC Converter for High Step-up Applications [#905]*  
Ming Shang and Wang Haoyu   
, ShanghaiTech University, China

This paper presents a novel integrated dc/dc topology with a step-up output and a step-down output. A new control scheme is developed to regulate both outputs simultaneously. Compared with discrete configurations, the proposed integrated converter utilizes a lower number of switches due to the reuse of components. The converter characteristics are studied comprehensively. It is demonstrated that all MOSFETs are turned on at zero voltage with reduced switching losses. For the step-up stage, the converter provides a high boost ratio and is able to clamp the switch voltage spikes. For the step-down stage, the steady-state characteristics and the dynamic performances are similar to that of the conventional buck converter. Moreover, the step-down output port can be extended to multiple ports, where the single-input-multiple-output (SIMO) version of converter can be derived. A 250 W, 42 V to 390 V and 15 V converter prototype is designed, analyzed and tested. The experimental results are presented to verify the feasibility of the topology.

**P2502***A Survey on Voltage Boosting Techniques for Step-Up DC-DC Converters [#1041]*  
Mojtaba Forouzesh, Yam P. Siwakoti, Saman A. Gorji, Frede Blaabjerg and Brad Lehman   
, Aalborg University, Denmark; Swinburne University of Technology, Australia; Northeastern University, United States

Step-up dc-dc converters are used to boost the voltage level of the input to a higher output level. Despite of its features such as simplicity of implementation, the fundamental boost dc-dc converter has shortcomings such as low boost ability and low power density. With these limitations, researches on new voltage boosting techniques are inevitable for various power converter applications. This can be achieved either by additional magnetic or by electric field storage elements with switching elements (switch and/or diode) in different configurations. Such combination of primary voltage boosting techniques and topologies are large, which at times may be confusing and difficult to follow/adapt for different applications. Considering these aspects and in order to make a clear sketch of the general law and framework of various voltage boosting techniques, this paper comprehensively reviews different voltage boosting techniques and categorizes them according to their circuit performance.

**P2503***Analysis and Design of a Current fed Non-isolated Buck-Boost DC-DC Converter [#1152]*  
Ashok Kumar, Roja Peri and Parthasarathi Sensarma   
, Indian Institute of Technology, Kanpur, India

This paper presents the analysis and design of a non-isolated, current-fed buck-boost DC-DC converter. The converter is capable of performing both buck and boost operations with zero-ripple input current. An active-clamp circuit is used to recycle the energy stored in the leakage inductance, which minimizes the voltage stress of main switch and provides zero voltage switching at turn-on. The circuit configuration, operation principle and design considerations of the converter in boost mode are discussed in detail. Experimental results for a 300 W hardware prototype with an input voltage range of 40-50 V and regulated output voltage of 400 V are obtained for validation of the converter topology.

**P2504***Impulse Commutated Current-fed Three-phase Modular DC/DC Converter for Low Voltage High Current Applications [#753]*  
Akshay Rathore and Radha Sree Krishna Moorthy   
, Concordia University, Montreal, Canada; National University of Singapore, Singapore

Current-fed converters with their innate boost nature, short circuit protection etc. offer enormous potential for high current and high gain applications. To resolve the issue of turn-off spike severe in current-fed converters, this paper proposes a commutation strategy termed as impulse commutation in a three-phase current-fed full bridge converter. This simple and cost-effective technique employing high frequency (HF) parallel capacitors achieves load adaptive zero current switching (ZCS) of the primary semiconductor devices. Variable frequency modulation ensures output voltage regulation and power transfer with source voltage variations. Modularity and scalability of the full bridge converter improves the converter reliability and a compact light-weight system can be easily realized.

**P2505***Comparative evaluation of capacitor-coupled and transformer-coupled dual active bridge converters [#1052]*  
Parikshith Channegowda and Giri Venkataramanan   
, University of Wisconsin-Madison, United States

Dual Active Bridge (DAB) converters are emerging to become the preferred high power DC-DC conversion topology to satisfy the requirements of modularity, high voltage transfer ratio, high efficiency and bidirectional power transfer capability. However transformer design for DAB converters remains a challenging problem, especially for high voltage conversion ratio and higher switching frequencies. Capacitor-coupled transformer-less DC-DC converters capable of arbitrary high voltage transfer ratio with reasonable efficiency have been recently introduced. The voltage gain in this case is achieved by series combination of capacitor coupled active bridge modules. This paper introduces the capacitor-coupled dual active bridge converter and compares it with the traditional transformer-coupled dual active bridge converter. A brief overview of the analytical models of both transformer- coupled and capacitor-coupled DAB converters is presented and the important design factors of both topologies are identified, followed by a comparative evaluation of a published benchmark design with details of all the power circuit components.

**P2506***Planar Transformer Winding Technique for Reduced Capacitance in LLC Power Converters [#1372]*  
Mohammad Ali Saket Tokaldani, Navid Shafiei and Martin Ordonez   
, University of British Columbia, Canada

Planar transformers (PTs) offer advantages over traditional wire-wound transformers including low-height, low leakage inductance, excellent thermal characteristics, Exceptional reproducibility and manufacturing simplicity. Despite these features, PTs have very high parasitic capacitance due to the large overlapping area and the small distance between consecutive layers. These parasitic capacitances can severely affect the performance of power converters and limit the application of PTs in high frequencies. In this paper, a new PT with very low parasitic capacitance is introduced to mitigate the problems that arise from the parasitic capacitances. The the superiority of the proposed PT is confirmed through finite element analysis (FEA) and the experimental measurements and it is shown that the proposed transformer has 21:2 times less intra and 16:6 times less inter-winding capacitance than traditional spiral PT. This significant capacitance reduction has a tangible effect on the performance of power converter and the experimental results of employing the proposed transformer in 1:2 kW LLC resonant converter shows considerable performance improvement of the converter in terms of common mode (CM) noise and light-loading voltage regulation.

**P2507***Topology and Controller of an Isolated Bi-Directional AC-DC Converter for Electric Vehicle [#720]*  
Beham Koushki, Praveen Jain and Alireza Bekhshai   
, Queen's University, Canada

An isolated, single-stage bidirectional AC-DC converter for electric vehicle battery charger is proposed. The topology utilizes two half-bridge circuits and a series resonant LC circuit in between. The proposed topology uses only six switches. Low component count in the circuit results in lower cost and volume. Control methods using variable phase-shift and duty-cycles of the half-bridge circuits are proposed. They transfer the desired power and obtain ZVS for all the switching instants while minimizing the RMS current through the resonant circuit and switches. ZVS operation of the circuit enables the switching frequency to increase, without increasing the switching losses. This will result in smaller reactive components and transformer. The proposed controllers also obtains the best performance out of the circuit. Simulation results with PSIM and experimental results to verify the theory have been done.

**P2508***High Efficiency LLC DCX Battery Chargers with Sinusoidal Power Decoupling Control [#722]*  
Dong-Jie Gu, Zhiliang Zhang, Yaqi Wu, Dong Wang, Handong Gui and Li Wang   
, Nanjing Univ. of Aeronautics and Astronautics, China; The University of Tennessee, United States

With the sinusoidal charging scheme, the large dc link capacitance of the onboard battery charger can be reduced significantly. However, the variable charging current together with the wide battery voltage range imposes serious challenge to maintain high efficiency throughout the whole charging procedure. This paper proposes a LLC dc to dc transformer (DCX) battery charger topology solution to improve the efficiency over the full battery voltage range. Furthermore, on the basis of the topology, a sinusoidal power decoupling control scheme is proposed to realize the front end PFC and sinusoidal output current at the battery side. A 1kW battery charger prototype was built to verify the benefits. For a battery voltage range from 64 V to 84 V, the efficiency of the proposed charger maintains above 95.8% and the peak efficiency is 96%. The dc link voltage ripple is only 12 V with a 22uF film bus capacitor, which is reduced by 97% compared with the conventional dc charging scheme.

**P2509***PWM Strategies with Duality between Current and Voltage Source AC/DC Converters for Suppressing AC Harmonics or DC Ripples [#175]*  
Junpei Isozaki, Kazuma Suzuki, Wataru Kitagawa and Takaharu Takeshita   
, Nagoya Institute of Technology, Japan

This paper presents duality of PWM (Pulse Width Modulation) strategies between current and voltage source AC/DC converters and the relation between PWM strategies for suppressing either AC harmonics or DC ripples. In addition, the authors propose the PWM strategies of a voltage source AC/DC converter which have the duality of the PWM strategies of a current source AC/DC converter without extra logic circuit. The validity of the PWM strategies is verified by experiments.

**P2510***Analytical Expression for Harmonic Spectrum of Regular Sampled Space Vector Modulated Rectifier Connected to IPM Generator [#455]*  
Jian Zhang, XuHui Wen, JinLong Li, Youlong Wang and WenShan Li   
, Institute of Electrical Engineering, CAS, China

The harmonic issue of generator rectifier system is discussed in this paper. A general method for determining the theoretical harmonic components of the regular sampled symmetrical SVPWM is presented. The analytical expression for SVPWM was validated by comparing the analytical calculated results with experimental measurements.

**P2511***A Systematic Topology Generation Method for Dual-Buck Inverters [#415]*  
Li Zhang, Tao Zhu, Lin Chen and Kai Sun   
, Hohai University, China; Tsinghua University, China

This paper proposes a systematic method of the topology generation rules to generate dual-buck inverter topologies based on the concept of power flowing routes splitting and reconstruction. By using these topology generation rules, not only the existing dual-buck inverter topologies, but also a family of new transformerless DBFBI topologies with high reliability are derived from conventional H-bridge inverter topologies. A dual-buck H6-type transformerless topology is analyzed in detail with operational modes given. A prototype of this topology is built to verify the operation principle, experimental results verify the effectiveness of the improved modulation strategy.

**P2512***Analysis and Control of Decentralized PV Cascaded Multilevel Modular Integrated Converters [#712]*  
David Scholten, Nesimi Ertugrul and Wen Soong   
, The University of Adelaide, Australia

Multilevel cascaded photovoltaic (PV) inverters can create interleaved voltage waveforms, allowing for reduced filter sizes and higher efficiencies, whilst still allowing for the maximum power point tracking (MPPT) of individual PV modules. However, unlike the micro inverter, a high gain boost converter is not required due to the series nature of the PV modules. To reduce wiring and installation costs in small scale applications, the compromise is a decentralised approach utilising a restrictive low bandwidth and intermittent communications link between the modular integrated converters (MICs), which limits MPPT. In this paper, a simplified decentralised control algorithm for the MPPT of multilevel cascaded MICs is proposed that covers both individual and global control of the prototype system. The limits of multilevel power sharing distributions are analysed and verified, exploring the fundamental limits of the cascaded topology. Additionally, the necessary communications update rate of the algorithm is analysed as the MPPT speed is varied, focussing on the repercussions that this has on the harmonic current and required global/local operational balance.

**P2513***Experimental Study of a SiC MOSFET based Single Phase Inverter in UPS Applications [#741]*  
Cheng Luo, Xinyu Wang, Tianyang Jiang, Richard Feng, Huiting Xin and Han Li   
, Eaton Corporate Research and Technology, China

Single phase uninterruptible power supply (UPS) has been widely used for a variety of critical load to overcome the disruption in utility power supplies. Wide band gap (WBG) power semiconductor devices, such as Silicon Carbide (SiC) finds its application in UPS systems due to its higher switching frequency, lower losses, and higher power density compared to Si devices. In this paper, a full SiC-based 2-level single phase inverter was simulated and tested for single phase UPS applications. The performance is compared with a Si-based 3-level single phase inverter. The simulation and experimental results show that SiC-based 2-level inverter can achieve better efficiency than Si-based 3-level inverter with reduced component counts and system complexity. The impact of switching frequency and filter inductor size on the SiC inverter efficiency is also investigated.

**P2514***Performance Analysis of a flexible multi-level converter for high voltage photovoltaic grid-connected power system [#232]*  
Lu Zhou, Li Wuhua, Hu Senjun, Luo Haoze, He Xiangning, Cao Fengwen, Zhang Chaoshan and Du Jiyuan   
, Zhejiang University, China; Aalborg University, Denmark; Suzhou Vocational University, China; XiAn Kai Tian Power Electronics Technical Co, China

Multi-level converters are widely employed in medium voltage grid-connected PV systems, since they feature better power quality and higher conversion efficiency compared with two-level converters. The conventional two-stage PV converter configuration with additional high step-up elements can satisfy the wide input voltage requirements, but results in reduced conversion efficiency and increased cost. In this paper, a flexible multilevel converter is proposed and its topology derivation process is introduced. The proposed flexible multilevel converter can adaptively work as a single-stage three-level NPC converter under high PV voltage and as a two-stage five-level converter under low PV voltage. Therefore, it realizes high conversion efficiency during a wide PV voltage variation. Furthermore, the modulation scheme of the presented converter is analyzed in detail. Moreover, the power losses with MATLAB/PLECS simulation and fault-tolerant performance of this converter is explored. Finally, a test bench is built to validate the theoretical analysis of the proposed flexible multilevel converter.

**P2515***Circulating Current Control for Carrier-Based Discontinuous Modulation in Inverters with Parallel Legs [#513]*  
Andre Nicolini, Antonio Ricciotti, Fernanda Carnielutti and Humberto Pinheiro   
, Federal University of Santa Maria, Brazil; Federal University of Rondonia, Brazil

This paper presents a discrete time controller for the circulating current of three-phase voltage fed converters with two magnetically coupled legs that uses carried-based discontinuous modulation. The discontinuous modulation produces multilevel equivalent PWM line-to-line output voltages with reduced harmonic distortion and equally distributes the commutations between the switches. A state machine is used to reduce the number of commutations. Using this state machine a non-linear controller is proposed to keep the circulating current close to zero. Moreover, it is important to mention that the implementation of the proposed modulation and controller are straightforward, requiring neither a complex hardware nor a high development effort. Furthermore, simulation and experimental results are presented to demonstrate the good performance of the proposed method.

**P2516***A Phase-Shift PWM-Controlled ZVS Boost Full-Bridge AC-AC Converter for High-Frequency Induction Heating Applications [#65]*  
Shuichi Sakamoto, Tomokazu Mishima and Chiaki Ide   
, Kobe University, Japan; Fuji Electronics Industry Company, Japan

This paper presents a new single-stage utility frequency ac (UFAC)-high frequency ac (HFAC) resonant power converter for high frequency induction heating(IH) applications. The newly-proposed ac-ac converter features a boost converter and full-bridge HF resonant inverter integrated circuit (Boost-Full-Bridge, BFB) with a source voltage sensorless control scheme. The experimental results of a 3.0,kW-40kHz prototype are demonstrated on zero voltage soft switching(ZVS) operations and steady-state characteristics based on the phase shift pulse-width-modulation (PS-PWM) power regulation, then the validity of the proposed ac-ac converter is revealed from a practical point of view.

**P2517***Control Approach for a Class of Modular Multilevel Converter Topologies [#951]*  
Dennis Karwatzki and Axel Mertens   
, Leibniz Universitaet Hannover, Germany

This paper presents a generalised control that can be applied to a class of modular multilevel converter topologies. The approach splits up into current control based on the state-space representation and branch energy balancing. For the branch energy balancing, an optimisation process leading to minimal additional current stress is presented. After describing the control approach independently from any specific topology, it is applied exemplarily to the Modular Multilevel Matrix Converter. A comparison with a previously published branch energy balancing for the Modular Multilevel Matrix Converter is conducted, and the control approach is verified by simulation and experimental results.

Poster Session: Control, Modelling and Optimization of Power Converters

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Pericle Zanchetta, Luca Solero

**P2701***Digital Autotuning Controller for Point-of-Load Converter Based on Non-Intrusive Start-up Transient Observer [#718]*  
M. Ali, K. H. Loo and Y. M. Lai   
, The Hong Kong Polytechnic University, Hong Kong

A new method for online estimation of power-stage parameters and autotuning of feedback controller for point-of-load (POL) converter is presented in this paper. The autotuning controller presented has been specifically developed to handle wide variations of the resonant frequency of LC output filter and the equivalent series resistance (ESR) zero of output capacitor. The resonant frequency of LC output filter and the time constant of output capacitor's ESR zero are estimated by examining the start-up transient response of converter and online measurement of steady-state output voltage ripple, respectively, hence the proposed method is non-intrusive and does not affect converter's normal operation. Based on these results, digital compensator is automatically tuned based on some user defined phase margin and crossover frequency to provide the desired transient response and output voltage regulation over wide variations of power-stage parameters. Simulation and experimental results from a 12 V-to-1.5 V, 22.5 W, 500 kHz digitally controlled POL buck converter are provided to verify the effectiveness of the proposed method.

**P2702***Control of D-STATCOM During Unbalanced Grid Faults Based on DC Voltage Oscillation and Peak Current Limitations [#764]*  
Arash Khoshooei, Javad Moghani, Jafar Milimonfared, Alvaro Luna, Ignacio Candela and Pedro Rodriguez   
, Amirkabir University of Technology, Iran; Technical University of Catalonia, Spain; Technical University of Catalonia / Abengoa Rese, Spain

The safe operation of grid connected power converters during abnormal condition is a key issue in order to guarantee its operation and to avoid undesired trips. In this paper different control methods for the operation of a D-STATCOM are evaluated, where the reference currents are determined in such a way that none of the phase currents goes over the limits, as well as the DC voltage fluctuations remain in safe operation limit. Therefore, the contribution of this paper lays on the combination of the DC voltage oscillations and the current limit control. As it is shown in the following, three different control strategies are evaluated. The amplitude of the oscillations which are superimposed on the DC voltage as well as peak amplitude of the phase currents are calculated for each, considering a generic imbalance in the network. The effectiveness of the presented control strategies are verified by simulating a D-STATCOM tied to an industrial distribution network. Moreover a scaled scenario has been reproduced experimentally which shows that the results cope well with the analytical equations and the simulation results..

**P2703***Staircase Modulation of Modular Multilevel Converters with Minimal Total Harmonic Distortion and Maximal Number of Output Voltage Levels [#831]*  
Sufei Li, Yi Deng and Ronald Harley   
, Georgia Institute of Technology, United States

This paper proposes a generalized staircase modulation method for modular multilevel converters (MMCs). Compared to high-frequency modulations, the staircase modulation has a lower switching frequency and losses, and lower dV-dt stresses for power electronics devices. By using Karush-Kuhn-Tucker (KKT) conditions, this paper proposes a method with rigorous proof to calculate the switching angles that is computationally efficient and achieves global minimal total harmonic distortion (THD) of phase voltages within the entire modulation index range. This method produces the maximal number of voltage levels (i.e., 2n+1, where n is the number of submodules in each arm) to further reduce the THD. Capacitor voltage balancing control is incorporated in the staircase modulation scheme. Simulation results validate the analysis.

**P2704***FPGA Implementation of Model Predictive Direct Current Control [#933]*  
Joel Vallone, Tobias Geyer and Eduardo Rath Rohr   
, EPFL, Switzerland; ABB Corporate Research, Switzerland

An FPGA implementation of Model Predictive Direct Current Control (MPDCC) is reported in this paper. A central scheduler enumerates switching sequences and assigns these to several explorer units, which predict the system response and compute their associated cost. The proposed FPGA design is scalable, modular and requires little hardware resources. A five-level active neutral point clamped inverter with a medium-voltage induction machine is considered. The MPDCC scheme controls the machine's stator currents, the neutral point potential and the inverter's phase capacitor voltages at a low switching frequency.

**P2705***Active Damping of LC Resonance for Paralleled Indirect Matrix Converter Based on Cascaded Control [#952]*  
Yang Xiao, Zheng Wang, Shuai You, Ming Cheng and Liang Xu   
, Southeast University, China; Aviation Key Laboratory of Science and Technolog, China

The indirect matrix converters (IMC) offer the advantages of high reliability and compactness in structure due to no large energy storage components in virtual DC side, and thus have a promising application in the future. However, the LC resonance caused by input filter is one reason keeps it from being utilized in industry. Different from pervious solutions of LC resonance damping for single IMC, this paper proposes an active damping strategy for the paralleled IMC with both interleaved operation and cascaded control of input LC filter. The key is to apply the closed-loop control of grid currents to generate the references for capacitor voltages, which are tracked by the inner capacitor voltage loop. By designing the control parameters properly, this method can not only suppress the LC resonance effectively but also offer accurate control of grid currents. In order to further mitigate resonance, the interleaved operation is applied to reduce specific order harmonic around resonant frequency of LC filter. No additional cost will be required for the proposed interleaved and cascaded control strategy. Furthermore, the feed-forward terms of voltage drop on filter inductor and capacitor currents are added to the control, in such a way that the decoupling effects between the d-axis and q-axis are removed and the dynamic response becomes better. Both simulation and experiments are given to verify the correctness and feasibility of the proposed strategy.

**P2706***Virtual Circuit Design of Grid-Connected Half-Bridge Converters with Higher-Order Filters [#1077]*  
Korawich Niyomsatian, Piet Vanassche, Bruno Hendrickx, Peter Tant, Jeroen Van den Keybus and Johan Gyselinck   
, Triphase, Universite libre de Bruxelles, Belgium; Triphase, Belgium; Universite Libre de Bruxelles, Belgium

This paper presents a structured design method for half-bridge converters with higher-order lossless output filters, focusing on the popular LCL filters. The method builds on the theory of terminated ladder networks and on a control algorithm actively emulating the ladder network termination. Given a desired transfer function, a normalized ladder network is accordingly synthesized and scaled to meet the physical requirements. The component sizing and the active damping of filter resonances are simultaneously tackled. The associated digital-control architecture for LCL filters is explained. A Kalman observer is employed to deal with the inherent sample delay. An LCL filter is designed based on the proposed method and is experimentally validated with the half-bridge converters operating as active front end. The grid reactive currents are stepped and the results show properly damped responses. The system has good disturbance rejection and is passive according to the simulated input admittance. The robustness of the system is also demonstrated by numerical sensitivity analysis. These excellent characteristics can facilitate the design of the upper-layer or incorporated outer-loop controller, and can enhance the performance of the complete system.

**P2707***Commutation Technique for High Frequency Link Inverter without Operational Limitations and Dead Time [#1639]*  
Minjeong Kim and Robert S. Balog   
, Texas A and M University, United States

An improved commutation technique for the ac-ac output converter circuit of a pulse width modulated high frequency link (HF-link) inverter is proposed in this paper. The high frequency link inverter converts a DC input voltage into line frequency AC output voltage using a high-frequency transformer for voltage step-up and galvanic isolation, without an intermediate rectification and dc bus. In this topology, there is a direct ac-ac converter which processes the HF-link square-wave voltage into the desired sinusoidal ac output voltage. To do this requires a commutation method to prevent shoot-through when output current changes direction or commutates from one switch to the next. Conventionally, dead time is used but this adds distortion to the output waveform. Previously a commutation technique without dead time was introduced but it required a number of assumptions on the inverter load impedance and link voltage characteristics that made it useful for a stand-alone R-L load but not practical for grid connection. The commutation method in this paper does not require dead time and does not impose any limitation on the output inductance and link voltage magnitude and frequency. Simulations were performed using MATLAB and Plexim, experimental verification used the dSpace1007 HIL platform.

**P2708***Research on the Current Control method of N-paralleled Converter System for the High-Power Inductor Tester [#875]*  
Cheng Nie, Wanjun Lei, Huajia Wang, Mingfeng Chen and Yue Wang   
, Xian Jiaotong University, China; STATE GRID Electric Power Research Institute, China

This paper develops the N-paralleled converters with LCL filter system model and expands the virtual resistor control method for harmonic current control. Power electronic converter can be controlled as a current source. For some application the current source can be used to test the inductor characteristic, such as temperature rise, noise or vibration. While in some cases, several converters are connected in parallel to increase the output current amplitude. The N-paralleled converters with LCL output filter system presents complex resonances feature. And the output current of the system becomes out of control. This paper develops the closed-loop model of N-paralleled converters with the LCL filter system and reveals the output current amplification by analyzing the resonance feature of the system at first. Then the virtual resistor based current control method is expanded in the harmonic current control. For the application of N-paralleled converters with an LCL filter system to test the inductor characteristic, the amplitude of output harmonic current need be considered carefully. With the optimal virtual resistor value the output harmonic current can also be controlled well. Simulation and experimental results prove the validation of the system model and optimization for damping resistor value.

**P2709***Modeling and Bifurcation Analysis of Converters with Power Semiconductor Filter [#976]*  
Wing-to Fan and Shu-hung Chung   
, City University of Hong Kong, Hong Kong

An input filtering technique, named as Power Semiconductor Filter (PSF), has been previously proposed. Such solid-state filter can eliminate or reduce the use of bulky passive filters, so as to increase the power density of the entire converter. This paper will investigate into the bifurcation phenomena with the PSF using a peak-voltage modulator to regulate the voltage across the SPD. Detailed sampled-data modeling and stability analysis will be given. To tackle the occurrence of bifurcation, a compensation ramp introduced into the peak-voltage modulator will be proposed. The behaviors with and without the compensation ramp in the modulator will be demonstrated on a 48W, 40-140V / 24V buck converter. By studying the eigenvalue locus on the z-plane, the models can predict the onset of limit cycles and illustrate how the compensation ramp can make the locations of the eigenvalues lie within unit cycle.

**P2710***Suppression of Circulating Current in Paralleled Inverters with Isolated DC-link [#167]*  
Hyun-Sam Jung, Jeong-Mock Yoo, Seung-Ki Sul, Hak-Jun Lee and Chanook Hong   
, Seoul National University, Korea (South); LSIS Co., Ltd., Korea (South)

In this paper, it is described how the circulating current flows between inverters which have isolated DC-link such as Cascaded H Bridge (CHB) topology, when they operating in parallel. In this case, Zero Sequence Circulating Current (ZSCC) flowing through shared DC-link cannot flow between inverters in parallel. However, circulating current is provoked by asynchronous switching instant of devices and difference of DC-link voltages of parallel inverters. The circulating current should be suppressed by sharing inductor which is inserted between inverters. Generally, all of the inverters should synthesize the same output voltage reference for load current control, to minimize the size of this sharing reactor. However, this conventional method cannot guarantee to diminish circulating current in the transient state and even in the steady state. In this paper, to reduce circulating current, after deriving circulating current model, circulating current control method is devised based on the model. This proposed algorithm is applied to Active Front End 5Level-CHB inverter system for medium voltage drive. Simulation and experimental results are provided to verify the effectiveness of the proposed control scheme.

**P2711***Small-Signal Model for the ISOP DC-DC Converters in the 5-Level T-Rectifier [#375]*  
Marco Di Benedetto, Alessandro Lidozzi, Luca Solero, Fabio Crescimbini and Petar Grbovic   
, ROMA TRE University, Dept. of Engineering, Italy; Roma TRE University, Dept. of Engineering, Italy; Huawei Energy Competence Center Europe (HECCE), Germany

A small-signal model for the Input-Series Output-Parallel (ISOP) DC-DC converters is developed in this paper. The proposed model is obtained applying the State-Space Averaging technique. The ISOP DC-DC converter consists of multiple DC-DC modules connected in series at the input and in parallel at the output. In this paper, the ISOP DC-DC converters are used in combination with the 5-level unidirectional T-Rectifier for electric generating units in More Electric Aircraft systems. The small-signal model for the ISOP DC-DC converters has been verified through the direct comparison with the converter full digital-switching model, realized in the Matlab/Simulink environment. Simulation results exhibit a good agreement between small-signal model and switching model.

**P2712***DC Bus Splitting Voltage Feedforward Injection Method for Virtually-Grounded Three-Phase Inverter [#526]*  
He Yuanbin, Chung Shu-hung, Ho Ngai-man, Wu Weimin and Fan Wing-to   
, City University of Hong Kong, Hong Kong; University of Manitoba, Canada; Shanghai Maritime University, China

The virtually-grounded grid-connected voltage-source three-phase inverter has b been proven to be more effective in alleviating the common-mode noise than the one without the virtual ground and in extending the utilization of DC bus voltage, as compared to the four-wire configuration. However, similar to the four-wire configuration, such virtually-grounded configuration would have DC bus unbalance, which would cause modulation saturation and output current distortion. Typically, two splitting capacitor voltages are measured and compared to produce a common-mode DC bias voltage to the output voltage of the inverter and thereby eliminate such effect. To reduce the number of sensors, a DC voltage feedforward injection method, which utilizes the intra-cycle average value of the duty cycles of the gate signals, is proposed to mitigate possible modulation saturation and output current distortion under the unbalanced condition of DC splitting voltage. A 3kW prototype has been built and evaluated to investigate the effectiveness of the proposed method.

**P2713***High Performance SiC Power Block for Industry Applications [#546]*  
Xu She, Rajib Datta, Maja Harfman Todorovic, Gary Mandrusiak, Jian Dai, Tony Frangieh, Philip Cioffi, Brian Rowden and Frank Mueller   
, GE Global Research, United States

SiC power devices have been optimized in performance over the past decade. However, wide industry adoption of SiC technology still faces challenges from system design perspective. This paper demonstrates an integrated air-cooled three phase SiC power block for industrial applications comprising high performance gate driver, low parasitic layout, optimized thermal management, as well as a flexible control platform. Experimental results are provided to demonstrate the superior performance of the design.

**P2714***Switching Angles Generation for Selective Harmonic Elimination by Using Artificial Neural Networks and Quasi-Newton Algorithm [#632]*  
Kehu Yang, Jun Hao and Yubo Wang   
, China Univ. of Mining and Tech., Beijing, China

A hybrid method based on artificial neural networks (ANNs) and Quasi-Newton algorithm is proposed to generate the switching angles for selective harmonic elimination (SHE), which makes a compromise among the memory consumption, executing efficiency and the solution precision. Unlike the other ANNs based methods which use ANNs to directly give the final switching angles, this hybrid method just uses ANNs to give the initial values, which lowers the precision requirement on training the ANNs, so, the number of the neurons can be reduced and less on-chip memories are required. Then, the Quasi-Newton algorithm is used to solve the exact switching angles from the initial values given by the ANNs, which guarantees the solving efficiency and the solution precision. The case of 11-level staircase modulated converter is studied by using the single-layer back-propagation (BP) neural networks. The trained neural networks have only 9 neurons in the hidden layer and the output initial values can meet the convergent requirement of the Quasi-Newton algorithm in the full range of modulation index. The total executing time is about 70ms on a STM32F407 microcontroller, as the executed code is automatically generated by MATLAB, the executing time could be further reduced if the code is manual optimized. Experiment results are also shown to verify the correctness of the switching angles generated by the proposed hybrid method.

**P2715***Minimum RMS Current Operation of the Dual-Active Half-Bridge Converter using Three Degree of Freedom Control [#1262]*  
Shiladri Chakraborty, Shailesh Tripathy and Souvik Chattopadhyay   
, Electrical Engineering Department, IIT Kharagpur, India; Electrical Engineering Department, NIT Rourkela, India

This paper discusses how triple duty-ratio control can be used to operate the Dual Active Half-bridge converter with the least possible transformer RMS current. Following introduction of all possible modes of operation, results from a numerical optimization-based approach are used to identify the best mode. Using information gleaned from careful observation of simulation results corresponding to the minimum current trajectory in this mode, key insights regarding circuit conditions to be satisfied for optimal operation are obtained. This information is used to propose the framework of a 3D modulation strategy, which operates with minimum RMS current and is also found to ensure ZVS of all devices. Thus the proposed modulation scheme offers significant efficiency advantages over simple phase-shift (1D) control or 2D asymmetric control, particularly at light loads and in applications with widely varying voltage-ratios.

Poster Session: Electrical Machines

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Bruno Lequesne, Mohammad Islam

**P2901***Comparison of Torque Characteristics in Permanent Magnet Synchronous Machine with Conventional and Herringbone Rotor Step Skewing Techniques [#1050]*  
Weizhong Fei, Patrick Chi Kwong Luk and Wenyi Liang   
, Cranfield University, United Kingdom

Torque characteristics, such as torque ripple and average torque, are of particular importance and primary concern during the design stage of permanent magnet synchronous machines for many high-performance applications. Thus, various design techniques have been developed and implemented to improve the torque characteristics in permanent magnet synchronous machines. The impacts of rotor step skewing techniques including both conventional and herringbone styles on the torque characteristics in permanent magnet synchronous machine are comprehensively investigated and compared by analytical approach, synthesized two-dimensional and three-dimensional finite element analysis in this paper. The results have shown that both the conventional and herringbone rotor step skewing techniques can significantly reduce the torque ripple with a slight compromise on the average torque output. Despite the herringbone rotor step skewing technique is less effective than the conventional one on cogging torque reduction from three-dimensional finite element analysis, it actually can result in higher average torque with smaller torque pulsations in the proposed permanent magnet synchronous machine with load conditions. Finally, experiments on the prototype machines under open-circuit conditions are carried out to validate the estimated results and findings.

**P2902***Six-Leg Dc-Link Rectifier/Inverter for Two-Phase Machines [#1082]*  
Nayara Brandao de Freitas, Cursino Brandao Jacobina and Alexandre Cunha Oliveira   
, Federal University of Campina Grande, Brazil

This paper proposes two different configurations of two-phase induction motor drives. These topologies utilize a single-phase supply to feed a two-phase machine/load and are more suitable when the amplitude of the load voltage is half the amplitude of the grid voltage. One of the topologies is transformerless and the other is transformer-based. The drive systems provide power factor control and DC-link voltage control. Pulsewidth modulation techniques for the converter control are discussed. Simulation and experimental results are provided to illustrate and compare the operation of the systems.

**P2903***RSM-DE-ANN Method for Sensitivity Analysis of Active Material Cost in PM Motors [#1275]*  
Alireza Fatemi, Dan Ionel, Nabeel Demerdash, Steve Stretz and Thomas Jahns   
, Marquette University, United States; University of Kentucky, United States; Regal Beloit Corporation, United States; University of Wisconsin-Madison, United States

In this paper, a numerical technique is developed for sensitivity analysis of active material cost (AMC) in PM motors with distributed and fractional slot concentrated windings. A comprehensive analysis is carried out to identify how the optimal design rules and proportions of IPM motors with sintered NdFeB magnets vary with respect to the changes in the commodity prices of permanent magnet material, copper, and steel. The sensitivities of the correlations between the design parameters and the AMC with respect to the commodity price ranges are investigated based on response surface methodology (RSM) and large-scale design optimization practice using differential evolution (DE) optimizer. An innovative application of artificial neural network (ANN)-based design optimization is introduced. Multi-objective minimization of cost and losses is pursued for an overall of 200,000 design candidates in 30 different optimization instances subjected to different cost scenarios according to a systematic design of experiments (DOE) procedure. An interesting finding is that, despite common expectations, the average mass of steel in the optimized designs is more sensitive to changes in the commodity prices than the masses of copper and rotor PMs.

**P2904***Modeling, simulation and performance evaluation of caged permanent magnet motors fed by variable speed drives (VSDs) [#507]*  
Sara Ahmed, Darren Tremelling, Zi-Ang (John) Zhang, Nicolas Frank, Robert McElveen and Kim Hongrae   
, Virginia Polytechnic Institute and State Univers, United States; ABB Inc., United States; Binghamton University-SUNY, United States; Baldor Electric company, United States

With increasing demand for higher efficiency, engineers are looking for an alternative solution to replace induction motors (IMs) in many applications. One of the very promising topologies is the permanent magnet (PM) motor with a squirrel cage on the rotor, which is referred to as the cage rotor PM motor in this paper. Based on the literature survey, the cage rotor PM motors have been studied and compared to IMs for direct on-line applications. Some studies also investigated the performance of line start PM motors (LSPMs) using a conventional VSD by comparing it to an IM using the same VSD. The comparative evaluation shows that, in most operating conditions, the LSPM drive provides better performance (usually higher efficiency) than the IM drive. In this paper, a d-q dynamic analytical model of the cage rotor PM motor is derived. The model is intended to be used in place of finite element analysis (FEA) and for purposes of control development. The model is implemented in Matlab/Simulink and used to study the behavior of different types of the cage rotor PM motor; line-start PM and light cage PM motors, when fed by a standard, scalar controlled drive. The analytical results are verified against the FEA, which shows excellent agreement.

**P2905***An Improved Conformal Mapping Aided Field Reconstruction Method for Modeling of Interior Permanent Magnet Synchronous Machines [#611]*  
Lei Gu, Mehdi Moallem, Shiliang Wang, Devendra Patil and Babak Fahimi   
, University of Texas at Dallas, United States; Isfahan University of Technology, Iran

An improved field reconstruction method (IFRM) to model interior permanent magnet synchronous machine (IPMSM) is proposed to reduce computation time. In modeling IPMSM with conventional FRM, in order to include slotting effect, the basis function at various rotor positions has to be obtained and stored which increases the workload. The saturation and slotting effect can be avoided by employing conformal mapping (CM) method which maps the slotted stator into a slotless structure. As a result, only one set of basis functions at one rotor position would be necessary. The slotting effect is modeled as equivalent permeability which includes the information of rotor position. Hence, the field density distribution in the slotted structure is the product of the flux density distribution of slotless structure and the equivalent permeability. FEA simulation is conducted to evaluate the results from improved FRM and to validate the effectiveness of the IFRM.

**P2906***Hybrid Excited Vernier PM Machines with Novel DC-Biased Sinusoidal Armature Current [#730]*  
Shaofeng Jia, Ronghai Qu, Jian Li, Dawei Li and Haiyang Fang   
, Huazhong University of Science and Technology, China

In this paper, a novel class of hybrid excitation, stator vernier permanent magnet (VPM) machines (HE-VPM) are proposed. The proposed machines are with salient rotor structure, stator located PMs, and concentrated armature windings. Therefore, the superiority of the proposed machine is robust rotor structure, short and non- overlapping end-winding, and easy heat dissipation. Besides, a novel DC-biased sinusoidal current, which contains an alternating current (AC) component and a direct current (DC) component, is applied, with this novel current, a novel hybrid excited VPM machines without additional field windings are obtained. The simulation results shows that the proposed machines exhibit higher torque density, power factor, and efficiency, Also, the constant power operation range is broadened, as the injected DC biased current can weaken or enhance the exciting fields at high/low speed. Finally, a prototype has been designed and under built, and the corresponding experiments will be added later.

**P2907***Calculating the Electromagnetic Field and Losses in the End Region of Large Synchronous Generators under Different Operating Conditions with Three-Dimensional Transient Finite Element Analysis [#851]*  
Sufei Li, Noris Gallandat, J. Rhett Mayor and Ronald Harley   
, Georgia Institute of Technology, United States

The significant losses in the end components due to the leakage magnetic field excited by the armature and field end windings can result in partial overheating and is an important consideration in the design of large synchronous generators. This paper describes an approach based on the three-dimensional (3D) transient finite element analysis (FEA) to determine the fields and losses in the generator end region. Taking the nonlinear anisotropic properties of the stator core, as well as the slitting and stepping shape of core-end packets into consideration, the electromagnetic field and loss distribution in the end region is calculated. The method is validated by the agreement found between the temperatures predicted by the 3D stationary thermal FEA and the temperatures obtained from a physical measurement at various points in the generator. Then, the field and loss distributions in the end region under the open- circuit test condition, power factor lagging condition and leading condition are analyzed and compared using the proposed transient 3D FEA method.

**P2908***Electrical Propulsion System Design of Chevrolet Bolt Battery Electric Vehicle [#1210]*  
Faizul Momen, Khwaja Rahman, Yochan Son, Bonho Bae and Peter Savagian   
, General Motors Corporation, United States

A permanent magnet synchronous motor (PMSM) motor is used to design the propulsion system of GMs Chevrolet Bolt battery electric vehicle (BEV). Magnets are buried inside the rotor in two layer V arrangement. The Chevrolet Bolt BEV electric machine rotor design optimizes the magnet placement between the adjacent poles asymmetrically to lower torque ripple and radial force. Similar to Chevrolet Spark BEV electric motor, a pair of small slots are stamped in each rotor pole near the rotor outer surface to lower torque ripple and radial force. Rotor design optimizes the placement of these slots at different locations in adjacent poles providing further reduction in torque ripple and radial force.

**P2909***Optimizing PM Coverage Ratio in Flux Concentrating Axial Flux Machine [#1583]*  
Minhyeok Lee, Kwanghee Nam and Jaehong Kim   
, POSTECH, Korea, Republic of; Chosun University, Korea, Republic of

A two-stator, one-rotor axial motor is considered for bike applications. It has a 24 slot 20 pole structure, and concentrated pole windings. Two stator cores are made with the laminated sheets instead of the soft magnetic composite (SMC). PMs are magnetized to the circumferential direction for concentrating the PM flux. The air-gap field is analyzed based on a simplified 2D model, and is solved for optimal permanent magnet (PM) ratio. The optimum PM coverage ratio is determined based on 3D FEM results. A prototype motor was built, and back EMF was tested.

**P2910***Detailed Analytical Modelling of Fractional-Slot Concentrated-Wound Interior Permanent Magnet Machines for Prediction of Torque Ripple [#193]*  
Mohammad Farshadnia, Muhammad Ali Masood Cheema, Rukmi Dutta, John Fletcher and Muhammed Fazlur Rahman   
, University of New South Wales, Australia

The standard dq model of interior permanent magnet machines is based on the assumption of sinusoidal machine parameters. This assumption is flawed especially when a fractional-slot concentrated-wound stator is utilized. In order to address this deficiency, in this paper the non-sinusoidal machine parameters are modelled in the abc-system. An extended dq-model is then proposed based on the derived non-sinusoidal machine parameters. New parameters are introduced in the proposed model and experimental tests are described for their determination. Based on the proposed extended dq-model, detailed equations for the average torque and torque ripple are proposed that specify the parameters involved in the production of different torque components. The proposed extended dq-model is used to predict the performance of a prototype fractional-slot concentrated-wound interior permanent magnet machine.

**P2911***A compact and light-weight generator for backpack energy harvesting [#1138]*  
Siavash Pakdelian   
, University of Massachusetts Lowell, United States

The reciprocating linear motion of a heavy backpack during walking has proved to be a viable source from which significant amount of electricity can be harvested. The energy harvesting systems proposed so far either use a mechanical rack and pinion to convert the linear motion to rotation or use a direct drive permanent magnet linear generator. This paper makes the case for the use of a magnetic gear to convert the linear motion to rotation. Compared to the mechanical rack and pinion, the proposed system is expected to have less noise, friction, and maintenance requirement and to facilitate the packaging. Compared to a direct drive linear generator, the proposed system would be multiple times lighter and compacter. The principles of backpack energy harvesting are outlined and design specifications of the proposed system are derived. An initial design is presented along with some simulation results.

**P2912***Suspension Loss Measurement and its Reduction in Single-Drive Bearingless Motor [#1380]*  
Itsuki Shimura, Hiroya Sugimoto and Akira Chiba   
, Tokyo Institute of Technology, Japan

This paper presents a new estimation method of magnetic suspension loss in one degree- of-freedom (1DOF) actively positioned single-drive bearingless motors. In the 1DOF bearingless motors, only axial z-axis direction is actively positioned. The other axes, radial movements and tilting movements, are passively stabilized. Single-drive bearingless motors can generate both torque and active axial force in q- and d-axis currents, respectively, by only one three-phase inverter. In this paper, the magnetic suspension loss is estimated in experimental results. In addition, it is confirmed that the magnetic suspension loss is decreased with an adaptation of a zero power control.

**P2913***A Compact Single-Phase Adjustable-Voltage-Ratio Magnetoelectric Transformer [#1683]*  
Haosen Wang, Liya Qu and Wei Qiao   
, University of Nebraska-Lincoln, United States

Adjustable-voltage-ratio (AVR) magnetoelectric transformer is a new type of power transformer whose voltage ratio between the output and input can be adjusted continuously from the minimum value (e.g., zero) to the maximum value designed. Therefore, given an input voltage with fixed amplitude, the AVR transformer can output one or multiple AC voltages with continuously adjustable amplitudes from zero volts to the maximum value. In this paper, a new structure- compact single-phase AVR transformer is proposed. The configuration and working principle of the proposed AVR transformer are presented. Finite element analysis (FEA)-based simulation analysis and preliminary experimental results are provided to demonstrate the proposed novel transformer concept.

**P2914***Analysis of Common Mode Circuit of BDFG-Based Ship Shaft Power Generation System [#843]*  
Hongbin Yang, Hua Lin, Xingwei Wang and Guangzhi Yao   
, Huazhong University of Science and Technology, China

In brushless doubly-fed generator (BDFG)-based ship shaft power generation system, the two back-to-back converters bring two common mode voltage sources and BDFG's two sets of stator wingdings provide several common mode current branches, which make the common mode circuit complicated. This paper have listed the common mode current loops and proposed an equivalent common mode circuit model based on lumped parameters for the system. The common mode impedances of the system have been acquired by measuring and calculating. The common mode current loop consists of two sets of stator wingdings and two back-to-back converters has been discussed with emphases. Simulation and experimental results agree with each other well and they verify the validity of the proposed model and the analysis about common mode circuit.

**P2915***Replacing SPM by PMARel machines in low-speed high-torque applications [#580]*  
Nicola Bianchi, Alessandro Castagnini, Giulio Secondo and Pietro Savio Termini   
, Dept of Industrial Eng., University of Padova, Italy; ABB, Discrete Automation and Motion Division, Italy

The aim of this paper is to evaluate alternatives to Surface-mounted Permanent Magnet (SPM) machines in low-speed high-torque applications, such as elevator systems, grindstones and positioning systems, where the electrical motor is directly connected to the load. In particular, the potentiality of PM-Assisted Reluctance (PMAREL) machines is deeply investigated. The capability of an SPM motor (adopting either NdFeB or Ferrite magnets) is compared with those of PMAREL motors employing Ferrite magnets. Different solutions are considered, varying the number of slots and poles, taking into account both distributed and fractional-slot winding. The analysis highlights the satisfactory performance of the PMAREL motors with distributed winding. On the contrary, the configurations with fractional-slot winding exhibit worse torque quality, even though different results are found according to the machine periodicity.

**P2916***Rotor Eddy-Current Loss Minimization in High-Speed PMSMs [#839]*  
Haiyang Fang, Ronghai Qu, Jian Li and Bao Song   
, Huazhong University of Science and Technology, China

In high-speed permanent-magnet synchronous machines (PMSMs), the permanent magnets (PMs) are usually retained by high strength sleeves. Metallic sleeves are preferred in some cases where a high rotor stiffness is required. However, high frequency time and spatial harmonics of the air-gap field would induce considerable eddy-current losses in the conductive sleeve, and thus exposing the PMs to risk of overheating and demagnetization. In this paper an 80 kW, 80,000 rpm PMSM is designed for air blowers. The initial design and analysis show that the rotor is overheated due to the high rotor losses when a titanium sleeve is used. Some existing methods for rotor loss reduction, namely copper shield and grooving the sleeve, are investigated for the design. Furthermore, a hybrid sleeve, which contains an inner titanium cylinder and an outer cylinder made of carbon fiber composite (CFC), is also proposed for this machine. The performances of various sleeves are studied in detail, considering the rotor eddy-current losses, the mechanical stress, and the temperature rise. The conclusions may provide some references for the design of high-speed PMSMs.

**P2917***Design and Analysis of Rotating Diode Rectifier for Wound-Rotor Synchronous Starter/Generator [#1328]*  
Pang Ji, Weiguo Liu, Chenghao Sun, Jixiang Wang, Zan Zhang and Yu Jiang   
, Northwestern Polytechnical University, China; AVIC SHAANXI AERO ELECTRIC CO.,LTD, China

The structure of rotating diode rectifier were proposed in this paper to solve the excitation problem of brushless wound-rotor synchronous starter/generator. Rotating diode rectifier plays an important part of excitation system of main generator. Triple Rectifier was adopted to take the place of three-phase rectifier. The three phase armature windings connect to a full-bridge rectifier each other. Every full-bridge rectifier connects together in a series to provide field current for the Main Generator. Compared with three-phase rectifier, this new Rectifier can take advantage of all phase winding voltage at any moment, then the exaction fielding winding current of Main Generator will be increased. An experimental platform was built and experimental results verified the feasibility and advantages of the triple rectifier.

**P2918***Stator Tooth and Rotor Pole Shaping for Low Pole Flux Switching Permanent Magnet Machines to Reduce Even Order Harmonics in Flux linkage [#1407]*  
Dheeraj Bobba, Gerd Bramerdorfer, Yingjie Li, Timothy A. Burress and Bulent Sarlioglu   
, University of Wisconsin-Madison, United States; Johannes Kepler University Linz, Austria; Oak Ridge National Laboratory, United States

High-speed machines require structurally robust rotor to withstand high centrifugal forces. Flux switching permanent magnet (FSPM) machines are ideal for high speeds since they have a simple and robust rotor structure. They also utilize permanent magnet (PM) in the stator enabling them to achieve high power density. It is desirable to keep the operating frequency minimized to reduce core losses and cost of power electronics. A 6-stator slot, 4-rotor pole (6/4) FSPM machine has the lowest operating frequency for a three phase FSPM configuration but suffers from heavy harmonic distortion in flux linkage. This paper aims to identify structural modifications that can minimize the dominant 2nd order harmonic component to make the 6/4 configuration amiable for high-speed applications. The analysis and methods proposed in this paper will be useful

**P2919***Optimization of PM Volume in a PM-assisted Claw-Pole Motor for ISG Applications [#1559]*  
Bonkil Koo, Jeongki Kwon and Kwanghee Nam   
, POSTECH, Korea (South); Hyundai MOBIS, Korea (South)

Claw-pole motor has naturally 3D structure, because of the structural complexity. However, it was simplified as a 2D model by linear approximation. The rotor model of PMassisted claw-pole motor has permanent magnets, as well as a field winding. Then an electric equivalent circuit is developed with a current source and a voltage source. Further, the rotor core saturation problem is treated with a nonlinear resistance (reluctance) which depends on the field current. The resistances are obtained from 3D FEM results, and used for computing an optimal PM volume. A real machine was constructed based on the computation results, and tested in a dynamo with an inverter.

Poster Session: Electric Drives

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Uday Deshpande, Gianmario Pellegrino

**P3101***Improved Model Predictive Current Control of Permanent Magnet Synchronous Machines with Fuzzy Based Duty Cycle Control [#1239]*  
Amir Masoud Bozorgi, Mehdi Farasat and Seyyedmahdi Jafarishiadeh   
, Louisiana State University, United States

Model predictive current control uses a model of the machine and an appropriate cost function to indirectly control electromagnetic torque and reactive power. However, due to sensitivity of model predictive control (MPC) to system parameters, need for high sampling frequency, and high torque and flux ripples, this method is not employed in a wide variety of commercial drives. Incorporating the concept of duty cycle and applying two voltage vectors during a sampling period can reduce the torque and stator current ripples of a model predicative current controlled synchronous machine. In this paper, duty cycles of the voltage vectors are determined effectively using a fuzzy logic modulator. In addition, a full order Luenberger observer is designed for accurate estimation of motor variables in presence of parameter uncertainties. Matlab and real-time simulation results confirm the effectiveness of the proposed MPC.

**P3102***A Universal Restart Strategy for Induction Machines [#245]*  
Kibok Lee, Sara Ahmed and Srdjan Lukic   
, North Carolina State University, United States; ABB, United States

This paper presents an approach to implement the universal flying restart for an induction machine using a frequency search algorithm that determines the rotor speed so that the correct frequency and voltage can be applied to minimize the inrush current during the restart. This method only uses the measured phase current and the motor nameplate parameters, thus making it ideal for use with scalar-controlled motor drives. An additional benefit of the proposed approach is that the time to estimate the rotor speed is independent of the motor parameters, and is defined by the restart algorithm itself. Beyond the development of the algorithm, implementation issues will be considered to provide general guideline for the application of the developed algorithm.

**P3103***Active Disturbance Rejection Control of Linear Induction Motor [#348]*  
Francesco Alonge, Maurizio Cirrincione, Filippo D'Ippolito, Marcello Pucci and Antonino Sferlazza   
, DEIM - University of Palermo, Italy; University of South Pacific, Fiji, Fiji; ISSIA-CNR, Italy

This paper proposes the theoretical framework and the experimental application of the active disturbance rejection control to linear induction motors. Such a non-linear control technique can be viewed as a particular kind of input-output linearization control technique, where the non-linear transformation of the state is not a priori given by a model, while it is estimated on-line. Such an approach permits to cope with modelling errors as well as any uncertainty in the knowledge of the model parameters. The effectiveness of the proposed active disturbance rejection control law has been verified experimentally on a suitably developed test set-up.

**P3104***Super-Twisting Algorithm Based Sliding-Mode Observer with Online Parameter Estimation for Sensorless Control of Permanent Magnet Synchronous Machine [#276]*  
Donglai Liang, Jian Li and Ronghai Qu   
, Huazhong University of Science and Technology, China

Online parameter estimation could improve the performance of sensorless control. In this paper, a super-twisting algorithm (STA) based second-order sliding-mode observer (SMO) sensorless con-trol with online stator resistance estimation is proposed. The chattering problem and time delay, which could not be avoided in conventional SMO, are eliminated in this STA based second-order SMO. At the same time, a parallel online stator resistance estimation algorithm is proposed based on a first-order SMO. With the help of the online stator resistance estimator, the per-formance of the sensorless control is improved in terms of system stability and position accuracy. The stability of the online stator resistance estimator is proved by Lyapunov function. Finally, the STA based sensorless control method with online stator re-sistance estimation is verified and compared with conventional methods by simulation and experiments.

**P3105***High Dynamic Sensorless Control for PMSMs Based on Decoupling Adaptive Observer [#581]*  
Yongle Mao, Jiaqiang Yang, Tao Wang, Dejun Yin and Yangsheng Chen   
, Zhejiang University, China; Nanjing University of Science and Technology, China

Voltage reference that contains cross-coupling term between the q- and d-axis is commonly utilized as input of sensorless schemes, and this might cause coupling between speed and position estimation and deteriorate system dynamic performance, which is unacceptable in some applications such as electric vehicle and industrial robot. By employing decoupled voltage reference as observer input, this paper proposes a decoupling adaptive observer for permanent magnet synchronous motor (PMSM), with the estimated rotor speed and position regulated by current estimation errors of the q- and d-axis independently and simultaneously. Dynamic performance of the speed and position estimators, which can be treated as two separate Single-Input-Single-Output (SISO) systems, is analyzed based on their transfer functions, and explicit guidelines for observer gains determination are derived. Experimental tests are conducted on a 1.0 kW PMSM testing platform to verify the effectiveness of the proposed sensorless control approach.

**P3106***Position Sensorless Control of Switched Reluctance Motor Based on a Numerical Method [#683]*  
Fei Peng, Jin Ye and Ali Emadi   
, McMaster University, Canada; San Francisco State University, United States

In this paper, a new position sensorless control method for switched reluctance motor drives is proposed. Rotor position is initially calculated based on the flux linkage-position- phase current characteristics by numerical method. Then, a third-order phase locked loop considering the acceleration variation is designed to undermine the impact of current sampling noise and numerical residual error on the estimated rotor position. Simulation and experimental results show that the proposed position sensorless control method has achieved sufficient accuracy in terms of position and speed estimation.

**P3107***Operating-Envelop-Expandable Control Strategy for Switched Flux Hybrid Magnet Memory Machine [#1042]*  
Hui Yang, Heyun Lin, Z. Q. Zhu, Erxing Zhuang, Shuhua Fang and Yunkai Huang   
, Southeast University, China; University of Sheffield, United Kingdom

Memory machines (MMs) equipped with hybrid permanent magnets (PMs), i.e., NdFeB and low coercive force (LCF) PMs, combine the merits of acceptable torque capability at low speeds and efficiency improvement at high speeds. Meanwhile, the PM flux linkage can be flexibly adjusted with the aid of current pulses, which is desirable for variable speed applications. To effectively extend the constant power speed range (CPSR) with minimum required flux-weakening (FW) current injected by the inverter, a new control strategy is proposed and implemented on a switched flux hybrid magnet memory machine (SF-HMMM). The configuration and operating principle of the proposed machine are introduced first, followed by the establishment of the mathematical model. Afterwards, the proposed control strategy is described accounting for a whole operating envelop. Different FW regions will be numerically identified by calculating the transition speed. In FW region I, the conventional d-axis current-based and PM demagnetization FW schemes are integrated, while only the negative d-axis current injection is employed in FW region II. The proposed control strategy combines the distinct advantages of memorable flux and negative Id FW controls, leading to an effective extension of CPSR with improved efficiency as well as low requirement of inverter current. The proposed method is verified by experiments on the prototype machine.

Poster Session: Power Semiconductor Devices, Passive Components, Packaging, Integration, and Materials

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Giovanna Oriti, Enrico Santi

**P3301***Modelling the closely coupled cascode switching process [#1505]*  
Pablo F. Miaja, Sheng Jiang, Kean-Boon Lee, Peter A. Houston, Ivor Guiney, David J. Wallis, Colin J. Humphreys and Andrew J. Forsyth   
, University of Manchester, United Kingdom; University of Sheffield, United Kingdom; University of Cambridge, United Kingdom

The cascode combination of transistors is a simple and interesting way of turning a normally-on device into a normally-off one. Cascodes are usually used with wide bandgap materials such as gallium nitride (GaN) and silicon carbide (SiC) in which a wide bandgap normally-on device is connected to a silicon MOSFET. Integration of the different transistors to form a closely-coupled cascode leads to an improvement in the switching characteristics. By undertaking a detailed analysis of the closely-coupled cascode switching behaviour under constant current drive conditions, an insight into the role of the different parasitic capacitances and the current capability (related to the size) of the transistors can be obtained. This is of great importance when designing all-GaN die-integrated cascodes. Also, it provides a basis for comparing cascodes with single devices in terms of the Qg.Ron figure of merit.

**P3302***A 700-V Class Reverse-Blocking IGBT for Large Capacity Power Supply Applications [#159]*  
David Hongfei Lu, Hiromu Takubo, Hiroki Wakimoto, Toru Muramatsu and Haruo Nakazawa   
, Fuji Electric Co., Ltd., Japan

A 700-V class Reverse-Blocking IGBT (RB-IGBT) is developed for large capacity power supply applications inevitably accompanied with increasing parasitic inductance and high current slew rate relative to their medium capacity counterparts. Compared with 600-V RB-IGBT, the device allows high dynamic surge voltage and fast switching to reduce turn-off loss by 35% under an advanced T-type-NPC three level power module benchmark condition and by 17% from a loss analysis of a realistic three level rectifier stage in a generic power converter application. Furthermore, reduction of reverse-blocking leakage current to one-tenth also enables 25 deg. C higher operation junction temperature. A side effect of the developed device as a first step is a 0.15V increase in on-state voltage, making it gain no loss reduction in a three level inverter stage. Therefore, its reduction should be addressed in further work.

**P3303***Efficiency and Electromagnetic Interference Analysis of Wireless Power Transfer for High Voltage Gate Driver Application [#1044]*  
Jianyu Pan, Feng Qi, Haiwei Cai and Longya Xu   
, The Ohio State University, United States

Wireless power transfer (WPT) holds great potential to achieve strong galvanic isolation, compact size, and low parasitic capacitance in the power supply of gate driver. In this paper, a wireless power supply is designed and analyzed for high voltage gate driver application. The performance of the power supply in terms of power delivery, parasitic capacitance, and driver output is explored in the functional test.Meanwhile, electromagnetic interference (EMI) is investigated in both frequency and space distribution based on measurement and simulation. The experimental results demonstrate that the prototype successfully delivers power for gate driver board with an 80 mm air gap while the maximum transfer efficiency is kept around 90%. The parasitic capacitance brought by the air gap is only 1.72 pF, which significantly increases common mode impedance. Radiated EMI affects the frequency span around the resonant frequency, and its distribution regularity in space is clearly displayed by field curves in horizontal axis and vertical axis.

**P3304***Single Chip Enabled High Frequency Link based Isolated Bias Supply for Silicon Carbide MOSFET Six-Pack Power Module Gate Drives [#1680]*  
Rui Gao, Li Yang, Wensong Yu and Iqbal Husain   
, North Carolina State University, United States

Regarded as one of the most successful wide bandgap (WBG) devices, Silicon Carbide (SiC) metal oxide semiconductor field transistors (MOSFETs) are being considered in an increasing number of power electronics applications. One of those applications is the hybrid and electric vehicle (HEV EV) traction inverters where high efficiency and high power density is essential. From the system level perspective, the gate driver circuit design for such device is challenging considering the device's fast switching speed and compact system structure. This paper presents a low profile isolated bias supply design using commercially available components for the SiC MOSFET modules targeting an HEV EV traction inverter application. A single chip MAX 13256 is adopted to form the high frequency link for entire power module gate drive supply. Distributed transformer strategy is highlighted to provide multiple isolated output and compact structure with minimized parasitic capacitance between all the isolation barriers. The featured low profile optimization reduces the parasitic parameters that might deteriorate the system performance for the fast switching WBG devices. Moreover, the open-loop high-frequency link architecture allows easy configuration for customized output voltage level, polarity and higher reliability. A prototype gate driver has been built for 1.2 kV, 50 A SiC six pack MOSFET power module, and experimental results are presented.

**P3305***Reliability Assessment of SiC Power MOSFETs From The End Users Perspective [#91]*  
Vasilios Dimitris Karaventzas, Muhammad Nawaz and Francesco Iannuzzo   
, Dept. of Energy Technology, Aalborg University, Denmark; ABB Corporate Research, Sweden

The reliability of commercial Silicon Carbide (SiC) Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) is investigated, and comparative assessment is performed under various test environments. The MOSFETs are tested both regarding the electrical properties of the dies and the packaging properties of the devices. The results of each reliability stress are utilized not only for mutual comparison of SiC-based power commercial modules, but also as a tool to understand the underlying physical mechanisms of degradation. Towards this goal, the devices were placed under accelerate stress conditions, such as: high electric field, high temperature and high humidity. Finally, a preliminary judgment is performed on each kind of stress, based on the quality assessment of the semiconductor as well as the packaging material.

**P3306***Investigation of Collector Emitter Voltage Characteristics in Thermally Stressed Discrete IGBT Devices [#1296]*  
Syed Huzaif Ali, Serkan Dusmez and Bilal Akin   
, University of Texas at Dallas, United States

Discrete package Insulated Gate Bipolar Transistor (IGBT) devices are a popular choice for low-medium power converters. Although IGBT power modules have been extensively studied in literature, there exists a major gap for reliability study particularly for discrete devices. Current failure diagnostic tools are not mature enough for failure diagnosis and prognosis in real-time operation based on system condition monitoring. In order to move power conversion technologies forward reliably, this paper investigates the changes in on-state collector- emitter voltage drop (Vceon) of discrete IGBT devices exposed to thermal cyclic stress. Depending on the dominant aging mechanisms and device structure, Vceon variation trend is different. In this paper, Vceon variations of three different IGBT device types, namely, punch through, non-punch through and field stop, are continuously monitored during accelerated aging tests, and their relations to aging mechanisms are identified.

Poster Session: Emerging Technologies and Applications

Tuesday, September 20, 11:00AM-12:30PM, Room: Exhibit Hall, Chair: Jin Wang, Yaosuo "Sonny" Xue

**P3501***Transmission Characteristics Analysis of a Three-Phase Magnetically Coupled Resonant Wireless Power Transfer System [#749]*  
Jiang Chong, Liu Fuxin, Ruan Xinbo and Chen Xuling   
, Nanjing Univ. of Aeronautics and Astronautics, China

Multi-phase magnetically coupled resonant (MCR) wireless power transfer (WPT) technology has attracted wide spread attention recently, for it can not only reduce the sensitivity of system to the spatial scale effectively, but also maintain the high transmission efficiency and power in the middle distance. This paper presented an analytical equivalent model for a three-phase MCR WPT system under phase angle control method with different spatial locations between the sending coils and receiving coil. The mutual inductance formulas of the sending coils and receiving coil were derived. The relationship among the output power, transmission efficiency and the angular misalignments were analyzed in detail. Experiments have also been carried out to facilitate quantitative comparison and validate the theoretical analysis.

**P3502***Synthesis of Buck Converter Based Current Sources [#866]*  
Soumya Shubhra Nag and Santanu Mishra   
, Indian Institute of Technology Kanpur, India

Ripple free DC or AC current source can be implemented by operating a switching converter in current mode control and setting the switching frequency much higher than the operating frequency. However, due to presence of the output filter across the load, it exhibits deviation from the ideal output impedance characteristics of an ideal current source. In this paper, a DC and an AC current source are presented which provides low ripple output current without sacrificing the high output impedance characteristics of an ideal current source. The DC and AC current sources are realized using a buck converter and a voltage source inverter, respectively with a coupled LLLC output filter replacing the traditional LC output filter. The low ripple output current is obtained by utilizing the notch behavior of the coupled LLLC filter. The operating principle of the proposed current source structures are explained in details. The effects of passive component tolerance on the current ripple attenuation and output impedance is also discussed in details. The performances of the proposed current sources are validated using simulations and experiments. The proposed DC current source and sinusoidal AC current source shows very low ripple content at their output current.

**P3503***A Model for Coupling Under Coil Misalignment for DD Pads and Circular Pads of WPT Systems [#868]*  
Guangjie Ke, Qianhong Chen, Ligang Xu, Siu-Chung Wong and Chi.K. Tse   
, Nanjing University of Aeron. and Astro., China; Nanjing University of Aero. and Astro., China; Hong Kong Polytechnic University, Hong Kong

The coupling coefficient of a transformer is a key parameter affecting the performance of a wireless power transmission system. Based on the magnetic reluctance model under aligned condition, this paper gives an effective method for calculating the null coupling position, as well as a practical and accurate model for finding the coupling coefficient under coil misalignment and varying air gap. The null coupling position is determined by the horizontal offset when the flux of opposite direction that is intersected with the receiving coil is cancelled out. An empirical formula is given to correct the null coupling position. Based on the physics of coupling under misaligned conditions, a practical model for coupling is constructed. Transformers with DD structure and typical circular structure are fabricated for verification. Experimental measurement validates the model.

**P3504***Comprehensive Dynamic Modeling of a Solid-state Transformer Based Power Distribution System [#1129]*  
Md Tanvir Arafat Khan, Alireza Afiat Milani, Aranya Chakrabortty and Iqbal Husain   
, North Carolina State University, United States

This paper presents a physics based comprehensive dynamic model of a future power distribution system, termed as the FREEDM system, for plug-and-play interface of distributed renewable energy resources and distributed energy storage devices. The system allows for high penetration of renewable generation with energy storage at the distribution level. FREEDM system consists of an energy router, which is the power electronics based solid- state transformer (SST) that interfaces distributed generation, storage and local loads on the low voltage side with the medium voltage node of the distribution grid. In this paper, state-space modeling and dynamic performance of the SST is analyzed along with the renewable generation sources and storage components with the goal of studying the feasible operating points of the FREEDM system. The actual model of the single-SST system amounts to highly complex dynamics with more than hundred state variables. Singular perturbation based model reduction techniques are applied, thereby leading to a 70th order state-space average model suitable for AC and DC energy cell system sizing, stability analysis, and controller design. The analysis with the system model revealed the SST input stage system parameters have the dominant effect on the feasible operation region.

**P3505***Capability, Compatibility, and Usability Evaluation of Hardware-in-the-Loop Platforms for DC-DC Converter [#1198]*  
Shawn Maxwell, S M Rakiul Islam, Md. Kamal Hossain and Sung Yeul Park   
, University of Connecticut, United States

This paper evaluates the capability, compatibility, and usability of Hardware-in-the-Loop platforms for DC-DC converter. This was accomplished by interfacing the platforms with a physical power stage as well as a controller. The employed platforms are Hi-Rel Power-pole board, Texas Instruments Digital Controller, RTDS, OPAL-RT, dSPACE and Typhoon. Two sets of experimentation were performed: the power stage represented by the Power-pole board, RTDS, OPAL-RT, dSPACE, and Typhoon and the controller replaced by TI DSC, RTDS, OPAL-RT, dSPACE, and Typhoon. Three points of evaluation for a testing platform that are of interest to industrial researchers as well as academia are capability (speed or modeling capacity), compatibility (ease of porting models from other platforms), and usability (ease of use of software and hardware). This paper provides an introductory resource for research and education by providing results of a simple buck converter example.

**P3506***A Single Stage AC/DC Converter for Low Voltage Energy Harvesting [#1230]*  
Liang Yu and Haoyu Wang   
, ShanghaiTech University, China

In this paper, a novel ac/dc converter is proposed for low voltage, low power rectification applications. The proposed converter manages the energy harvested from micro-scale electromagnetic transducers. It integrates the conventional Boost and Buck-Boost topologies with a shared inductor, a bidirectional switch and two split filtering capacitors. The Boost and the Buck-Boost topologies function in the positive and negative half input cycles, respectively. The inductor is energized by being shorted with the input source through the MOSFET channel without using the diodes. This enables active rectification of low amplitude (below 0.7 V) ac voltages. Theoretical analysis, design considerations and control method are detailed. A 45 mW circuit prototype, which converts a 0.4 V peak, 100 Hz ac voltage to 3.3 V dc is designed and tested to verify the proof of concept.

Tuesday, September 20, 3:00PM-4:30PM

Poster Session: Renewable and Sustainable Energy Applications

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Euzeli Santos Jr., Johan Enslin

**P3701***Dynamic Battery Operational Cost Modeling for Energy Dispatch [#1549]*  
Qian Zhao, Aniq Ahsan, Ashwin M. Kambadkone and Meng Hwee Chia   
, Experimental Power Grid Center, Singapore; Oxford University, United Kingdom; National University of Singapore, Singapore

Battery Energy Storage Systems (BESS) have gained extensive application in both grid and microgrid applications. One major type of BESS are electrochemical batteries such as Lead-Acid and Lithium-Ion batteries which have limited number of lifecycles. The common way of considering their operation cost is using a constant value such as LCOE (levelized cost of energy). However, as shown herein, given the same amount of energy output, the battery lifecycle degradation, and thus the degradation cost, can vary at different operation conditions (voltage, current, power, state of charge (SOC)) by up to 6 times. Herein a model for the dynamic battery operation cost as a function of its dispatch power and SOC is developed. The model also considers the dependency of battery voltage on its current and SOC, which equivalently takes into account the dependency of its conversion efficiency on its power and SOC. Preliminary simulations demonstrate that using the proposed model, instead of the LCOE, for Microgrid operation optimization microgrid operation cost is lower by up to 12%.

**P3702***A Low Voltage Ride Through Control Strategy for Energy Storage Systems [#349]*  
Yeongsu Bak, June-Seok Lee and Kyo-Beum Lee   
, Ajou University, Korea (South); KRRI, Korea (South)

This paper proposes a low voltage ride through (LVRT) control strategy for energy storage systems (ESSs). The LVRT control strategies for wind turbine systems and photovoltaic systems have been researched until now. Regardless of the energy source, the main aim of the LVRT control strategies for a grid side converter is to inject the reactive power according to the gird code regulations. The main aim of the proposed LVRT control strategy for ESSs is the same as them; however, it additionally considers the case of charging state which cannot be taken into consideration in wind turbine systems and photovoltaic systems having unidirectional power flow. The proposed LVRT control strategy for ESSs determines not only the reactive reference current for injecting the reactive power but also the active reference current to contribute to a point of common coupling (PCC) voltage increase by considering the two operating condition of charging and discharging state. The validity of the analysis is verified by simulation results.

**P3703***Experimental Validation of the Solid State Substation with Embedded Energy Storage Concept [#1010]*  
Christian Klumpner, Mohamed Rashed, Dipankar De, Chintan Patel, Ponggorn Kulsangcharoen and Greg Asher   
, University of Nottingham, United Kingdom

This paper proposes the concept of integrating the energy storage within a Medium Voltage to Low Voltage solid state substation in order to provide new features compatible with the requirements from future more intelligent grids. The principles for the system development are presented and the role of each subsystem is explained. The experimental evaluation of the 1.9kVrms/25kVA substation with 1.5MJ of supercapacitor storage consists of subsystem tests showing the waveform quality, step transients as well as system tests of the efficiency, ride-through and power peak shaving operation.

**P3704***Understanding Dynamic Model Validation of a Wind Turbine Generator and a Wind Power Plant [#151]*  
Eduard Muljadi, Yingchen Zhang, Vahan Gevorgian and Dmitry Kosterev   
, National Renewable Energy Laboratory, United States

Regional reliability organizations require power plants to validate the dynamic models that represent them to ensure that power systems studies are performed to the best representation of the components installed. In the process of validating a wind power plant (WPP), one must be cognizant of the parameter settings of the wind turbine generators (WTGs) and the operational settings of the WPP. Validating the dynamic model of a WPP is required to be performed periodically. This is because the control parameters of the WTGs and the other supporting components within a WPP may be modified to comply with new grid codes or upgrades to the WTG controller with new capabilities developed by the turbine manufacturers or requested by the plant owners or operators. The diversity within a WPP affects the way we represent it in a model. Diversity within a WPP may be found in the way the WTGs are controlled, the wind resource, the layout of the WPP (electrical diversity), and the type of WTGs used. Each group of WTGs constitutes a significant portion of the output power of the WPP, and their unique and salient behaviors should be represented individually. The objective of this paper is to illustrate the process of dynamic model validations of WTGs and WPPs, the available data recorded that must be screened before it is used for the dynamic validations, and the assumptions made in the dynamic models of the WTG and WPP that must be understood. Without understanding the correct process, the validations may lead to the wrong representations of the WTG and WPP modeled.

**P3705***A Brushless Doubly-fed Generator Based on Permanent Magnet Field Modulation for Wind Power Generation [#454]*  
Yongjiang Jiang, Jianzhong Zhang, Shuai Xu and Xing Hu   
, Southeast University, China

A new brushless doubly-fed double stator double rotor (DSDR) generator based on permanent magnet field modulation for the wind power application is proposed in this paper. This generator adopted double stator to achieve the decoupling of the control winding and power winding. To improve the power density, a freely rotating rotor is introduced. To achieve the variable-speed constant-frequency operation and cancel the brush and slip ring, rotating field modulation ring is adopted to link with the wind turbine directly. In this paper, the operation principle of DSDR generator is detailed described. To verify the correctness of the principle, the performance of the DSDR generator is analyzed by the means of finite element analysis (FEA). The proposed DSDR generator owns the advantages such as low cost, low maintenance, high power density, high reliability, low speed direct driven, and good performance on grid fault ride-through. It has the potential on application of future large-scale wind power generation systems.

**P3706***Robust Sliding Mode Control for Permanent Magnet Synchronous Generator-Based Wind Energy Conversion Systems [#497]*  
Patrick Gu, Xin Wang and Max Reitz   
, Southern Illinois University Edwardsville, United States

As renewable energy resources such as wind become more prolific, the challenges in utilizing these resources to their full efficiency come to the forefront of power system engineers. Although the sustainability of such alternative energy resources is attractive, the ability to obtain satisfactory efficiency has been difficult until recent advances in nonlinear control technologies. The subject of this paper pertains to sliding mode control and its application in nonlinear electrical power systems as seen in wind energy conversion systems. Due to the robustness in dealing with unmodeled system dynamics, sliding mode control has been widely used in electrical power system applications. This paper presents first and high order sliding mode control schemes for permanent magnet synchronous generator-based wind energy conversion systems. Application of these methods for control using dynamic models of the d-axis and q-axis currents, as well as those of the high speed shaft rotational speed show a high level of efficiency in power extraction from a varying wind resource. Computer simulation results have shown the efficacy of the proposed sliding mode control approaches.

**P3707***A Partially-Rated Active Filter Enabled Power Architecture to Generate Oscillating Power From Wave Energy Converter [#1656]*  
Samir Hazra, Prathamesh Kamat and Subhashish Bhattacharya   
, North Carolina State University, United States

This paper proposes an active filter (AF) enabled power architecture to harness oscillating power from wave energy converter (WEC). The proposed power architecture consisting of a diode rectifier and a dc-dc converter along with the partially-rated active filter, is cost-effective compared to conventional fully-rated power converter in generating oscillating power. The architecture is suitable to generate power using both squirrel-cage induction generator (SCIG) as well as permanent magnet synchronous generator (PMSG). In the current work, over all system modeling and control strategy is described for a SCIG based system. Feasibility of the proposed system is validated through experimental implementation with an emulated WEC excited by practical ocean wave data. The proposed system can also be effectively utilized to generate varying power from the tidal energy converter (TEC).

**P3708***Hybrid Energy Storage System Comprising of Battery and Ultra-capacitor For Smoothing of Oscillating Wave Energy [#1688]*  
Samir Hazra and Subhashish Bhattacharya   
, North Carolina State University, United States

In this work, a hybrid energy storage system (HESS) comprising of ultra-capacitor and battery is proposed for smoothing oscillating power from wave energy conversion system (WECS). Using generated power data from an installed wave energy converter (WEC), each component of the proposed HESS is sized to optimize the cost of the energy storage. A control scheme is designed to regulate the power into battery and ultra-capacitor to deliver smoothed average power to the grid. Energy storage minimizes the grid side converter (GSC) rating and also improves the stability of the grid by not injecting the oscillating power. The control scheme is verified through MATLAB simulation using the power data from field with maximum power reaching around 500-kW and a combination of available ultra-capacitors and batteries. An experimental validation of the control scheme is presented with an ultra-capacitor based energy storage system in a grid-connected wave energy conversion system (WECS) with an induction motor emulating as WEC to drive an induction generator.

Poster Session: Smart Grid & Utility Applications

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Johan H Enslin, Euzeli Santos Jr.

**P3901***A Series-LC-Filtered Active Trap Filter for High Power Voltage Source Inverter [#1600]*  
Haofeng Bai, Xiongfei Wang, Poh Chiang Loh and Frede Blaabjerg   
, Aalborg University, Denmark

Passive trap filters are widely used in high power Voltage Source Inverters (VSI) for the switching harmonic attenuation. The usage of the passive trap filters requires clustered and fixed switching harmonic spectrum, which is not the case for low pulse-ratio or Variable Switching Frequency (VSF) Pulse Width Modulation (PWM). Switching harmonic compensating using auxiliary power converters has been proposed and investigated by researchers. Like the traditional Active Power Filers, the performance of the existing approaches depends on the extraction of the switching harmonics and the accurate current control of the auxiliary converter, which can be challenging considering that the switching harmonics have very high orders. In this paper, an Active Trap Filter (ATF) based on output impedance shaping is proposed. It is able to bypass the switching harmonics by providing nearly zero output impedance. A series-LC-filter is used to reduce the power rating and synthesize the desired output impedance of the ATF. Compared with the existing approaches, the compensated frequency range is greatly enlarged. Also, the current reference is simply set to zero, which reduces the complexity of the control system. Simulation and experimental results are provided to show the effectiveness of the proposed method.

**P3902***Constant DC-Capacitor Voltage-Control-Based Strategy for Harmonics Compensation of Smart Charger for Electric Vehicles in Single-Phase Three-Wire Distribution Feeders With Reactive Power Control [#859]*  
Fuka Ikeda, Kei Nishikawa, Hiroaki Yamada, Toshihiko Tanaka and Masayuki Okamoto   
, Yamaguchi University, Japan; National Institute of Technology, Ube College, Japan

This paper proposes a novel and simple harmonics compensation strategy that can control the fundamental reactive current in the previously proposed smart charger (SC) for electric vehicles (EVs) in single-phase three-wire distribution feeders (SPTWDFs). The proposed harmonics compensation strategy uses only constant dc-capacitor voltage control (CDCVC), which is typically used in grid-connected pulse-width modulated inverters including active power line conditioners. Calculation blocks of the load-side fundamental active-reactive currents and harmonic currents are not required. Thus the authors offer the simplest harmonics compensation strategy for the SC in SPTWDFs with reactive power control. The basic principle of the proposed control strategy is discussed in detail. A digital computer simulation is implemented to confirm the validity and high-practicability of the proposed harmonics compensation strategy using PSIM software. Simulation results demonstrate that balanced and sinusoidal source-currents with a predefined power factor of 0.9 on the source side, which is an acceptable value in Japanese home appliances, are achieved on the secondary side of the pole-mounted distribution transformer using a CDCVC-based algorithm during battery charging and discharging operations in EVs. Simulation results also demonstrate that maintaining the power factor at 0.9 reduces the capacity of the SC by 31.5 % compared with that of the SC with the previously proposed control strategy.

**P3903***A Series Active Damper with Closed-loop Control for Stabilizing Single-phase Power-Electronics-Based Power System [#911]*  
Dapeng Lu, Xiongfei Wang, Haofeng Bai and Frede Blaabjerg   
, Aalborg University, Denmark

Active damper is a promising solution to address the stability issues caused by the interaction between the parallel grid-connected converters, which are the results from the coupled grid impedance. To further improve that, this paper proposes a series active damper with closed-loop control. Unlike existing parallel active dampers that using a virtual damping resistance through detection and resonant controller, the series active damper can suppress the resonances with its external damping character in closed-loop control. Analysis on the damping impedance and closed-loop damping character are carried out. Simulation and experimental results are presented to verify the effectiveness of the proposed series active damper.

**P3904***A Grid-Interfaced Test System for Modeling of NiMH Batteries in a Battery-Buffered Smart Load Application [#1149]*  
Ahmed Zurfi and Jing Zhang   
, University of Arkansas at Little Rock, United States

Testing and modeling of batteries are essential to evaluate the performance and effectiveness of battery energy storage systems (BESS) in power system applications. The procedure of extraction and experimental verification of any battery model require a reliable and efficient testing system. In this paper, a programmable grid-interfaced battery test system for battery modeling in a frequency-controlled battery-buffered smart load application is proposed. The testbed is based on the same smart load experimental system which consists of a single phase bidirectional AC-DC converter, a DC-link, and a bidirectional DC-DC converter. The AC-DC converter is designed to control a bidirectional power flow between the AC-line and the DC-link. Therefore, the energy can be controlled effectively flowing between the battery and the power line during charge and discharge without significant power losses. This design realizes an energy-conserving electronic load by supplying the battery energy to the grid instead of dissipating it during discharge. To verify the functionality of the developed system, 3Ah, 1.2V NiMH batteries were tested for a Thevenin-based model identification. Then, a simulation of the identified model was implemented in MATLAB/Simulink to validate the model under the smart load charging and discharging conditions

**P3905***Impedance-Based Stability Analysis of DFIG [#209]*  
Tianyi Wang, Yi Xiao, Xueguang Zhang and Dianguo Xu   
, Harbin Institute of Technology, China

With the increased wind power installed capacity and higher penetration of wind power in the power system, challenges arises for the safety and stable operation of the power system and the wind power equipment. As the most widely used generator in the wind power system, the stability of doubly fed induction generator (DFIG) should be paid enough attention. This paper focuses on the stability analysis of DFIG, including modeling the equivalent input admittance of DFIG and small signal stability analysis for different grid conditions. Developing the input admittance model of DFIG is the key point of the research. The modeling is carried out in synchronous rotating frame in order to obtain the steady operation point. This paper firstly derives inherent input admittance matrix of the DFIG power stage based on the mathematical model of DFIG in synchronous rotating frame. The DFIG converter control system is also considered to develop the equivalent DFIG input admittance model introduced by control system. The linearized small signal model of PLL and inner current loop are deduced. Based on the derived equivalent DFIG admittance model and the grid impedance model, small signal stability analysis is carried out according to the generalized Nyquist stability criterion (GNC). In synchronous rotating frame, the grid side of the DFIG wind power system is expressed in the form of voltage source with impedance matrix, while the DFIG side is expressed in the form of current source with admittance matrix. The small signal stability of the wind power system can be predicted with the characteristic loci of the return ratio matrix. The validity of the theoretical analysis is verified by simulation.

**P3906***Online Variation of Wind Turbine Controller Parameters for Mitigation of SSR in DFIG based Wind Farms [#642]*  
Selam Chernet, Massimo Bongiorno, Gert Karmisholt Andersen, Torsten Lund and Philip Carne Kjaer   
, Chalmers University of Technology, Sweden; Vestas Wind Systems A/S, Denmark

The aim of this paper is to investigate the risk for Subsynchronous Resonance (SSR) conditions in Doubly Fed Induction Generator (DFIG) based wind farms connected to series-compensated transmission lines. The well-known IEEE First Benchmark Model for SSR studies is adopted and the impact of the turbine controller parameters on the risk for unstable conditions is analyzed . In particular, it is shown through frequency domain studies that a reduction of the closed-loop bandwidth of the current controller that regulates the rotor current effectively reduces the risk for SSR. Simulation results are presented to validate the theoretical findings.

**P3907***Three-Phase Single Stage Boost Inverter for Direct Drive Wind Turbines [#1060]*  
Akanksha Singh and Behrooz Mirafzal   
, Kansas State University, United States

In this paper, a new power electronics interface topology for Direct Drive Wind Turbines (DDWTs) to improve the system reliability and with a potential to decrease the size of the Permanent Magnet (PM) generator is presented. In the proposed topology the grid-side Voltage Source Converter in a traditional DDWT is replaced by a three-phase single-stage boost inverter. This enables the use of a low-voltage generator and thus allows design of a smaller sized generator. The current source inverter topology of the boost inverter also enables elimination of the dc-bus electrolytic capacitors. In this paper, a detailed reliability analysis of the existing power electronic interface along with that of the developed interface is presented. The control technique used for the system is described. The validity of the proposed system is supported by set of MATLAB/Simulink simulations on the closed-loop grid-tied system.

**P3908***Secondary Side Modulation of a Single-stage Isolated High-frequency Link Microinverter with a Regenerative Flyback Snubber [#1538]*  
Nareshkumar Kummari, Shiladri Chakraborty and Souvik Chattopadhyay   
, Electrical Engineering Department, IIT Kharagpur, India

This paper presents comprehensive analysis of a single-stage, isolated, high- frequency ac link based dc-ac converter suitable for PV microinverter applications controlled using phase modulation of the cycloconverter devices (secondary side modulation). A flyback-based regenerative clamp circuit is used for mitigating voltage-spikes on the secondary devices arising due to leakage inductance induced oscillations. Experimental results on a 225 W laboratory prototype are presented to illustrate the discussed principles.

**P3909***Frequency Characterization of Type-IV Wind Turbine Systems [#1579]*  
Nicolas Espinoza, Bongiorno Massimo and Carlson Ola   
, Chalmers University of Technology, Sweden

The continuous need for renewable energy sources is a driving force for a fast development of wind turbine technologies. It is well known that control interactions can arise if the wind farms and the interconnecting system, for example ac collector system or high voltage direct current (HVDC)-link, are not properly integrated. One tool to assess the stability of the system is to analyze the input impedance of the wind farm together with the connecting grid impedance. In this regard, this paper investigates the impact of different system parameters in the input admittance of the generating unit. The admittance is analyzed for a wide range of frequencies. Moreover, the passive and non-passive behavior of the admittance is highlighted and the risk of interaction between the wind turbine and other elements of the grid is discussed. The system under consideration consists of a multi megawatt type-IV wind turbine system and a fully-rated voltage source converter (VSC)-based testing equipment used as verification tool for frequency scanning. First, the mathematical model of the system and the scanning method are presented. The input admittance is calculated for a variety of operating conditions including variations of control settings such as phase-locked loop (PLL) and close-loop current control bandwidth and system parameters, such as the output filter configuration. Finally, the investigated methodology is verified using time-domain simulations and field test results

Poster Session: Datacenters and Telecommunication Applications

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Jin Wang, Yaosuo "Sonny" Xue

**P4101***Reliablity Assessment of Fuel Cell System - A Framework for Quantitative Approach [#1665]*  
Shinae Lee, Dao Zhou and Huai Wang   
, Norwegian University of Science and Technology, Norway; Aalborg University, Denmark

Hydrogen Fuel Cell (FC) technologies have been developed to overcome the operational and environmental challenges associated with using conventional power sources. Telecommunication industry, in particular, has implemented FC systems for the backup power function. The designers and manufacturers of such FC systems have great interest in verifying the performance and safety of their systems. Reliability assessment is designated to support decision-making about the optimal design and the operation strategies for FC systems to be commercial viable. This involves the properties of the system such as component failures, the system architecture, and operational strategies. This paper suggests an approach that includes Failure Modes and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and Reliability Block Diagram (RBD). For a case study, and the service lifetime of a commercial 5 kW Proton Exchange Membrane Fuel Cell (PEMFC) system is estimated for backup power applications, in terms of the critical components, subsystems and the whole system.

**P4102***New Soft-Switched Multi-Input Converters with Integrated Active Power Factor Correction for Hybrid Renewable Energy Applications [#863]*  
Sanjida Moury, John Lam, Vineet Srivastava and Church Ron   
, York University, Canada; Cistel Technology Inc., Canada

Hybrid renewable energy systems increase reliability, flexibility and utilization of renewable sources in power generation. In order to achieve high system efficiency and to reduce the overall circuit size, multi-input converters (MICs) have been introduced to replace the individual power converters used in the conventional hybrid renewable energy system. Power factor correction (PFC) is essential when the converter consists of an AC-powered input module, such as working with a wind turbine system or connected with the utility grid. This paper proposed a new class of quasi-resonant (QR) MICs for hybrid renewable energy systems. The proposed MICs are able to achieve high power factor and they require only one switch in each input module. All the switches are able to achieve soft switching turn-on and turn-off for both individual and simultaneous operations for different operating conditions. Simulation results are presented on a ZVS QR MIC with the integrated boost PFC for a 650W, 48V-output hybrid wind-solar energy system. Some experimental results are also provided on a proof-of- concept 200W prototype to demonstrate the features of the proposed circuit.

**P4103***FPGA Based Implementation of Control for Series Input Boost Pre-regulator Under Unequal Loading [#1655]*  
Anwesha Mukhopadhyay and Santanu Mishra   
, Indian Institute of Technology, Kanpur, India

Diode bridge rectifiers, though very popular as AC-DC converter pollutes the source by injecting harmonics. To adhere to power quality standards, modern rectifier comes with a UPF pre-regulator. Multi-level or series connected topology where several units of diode-bridge along with pre-regulator stage are connected in series is most suitable for high voltage, high power implementation. However maintaining equal output voltage for different stages under unequal loading is a challenge. This paper proposes a novel control technique to address this issue. Closed loop control of the series connected diode bridge rectifier with boost pre-regulator has been implemented in FPGA using the proposed strategy. Configuration of FPGA as digital controller makes the control faster, thus facilitates high frequency switching. High frequency switching is preferred for reducing ripple in inductor current which contributes to inductor size reduction. The proposed control scheme has been verified in laboratory using two series connected stages of diode bridge rectifier with boost pre-regulator which shows good regulation under unequal loading and dynamic load variation.

Poster Session: Transportation Electrification Applications

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Jin Wang, Yaosuo "Sonny" Xue

**P4301***Separating Key Less Well-Known Properties of Drive Profiles that Affect Lithium-ion Battery Aging by Applying the Statistical Design of Experiments [#704]*  
Ruxiu Zhao, Larry Juang, Robert Lorenz and Thomas Jahns   
, University of Wisconsin-Madison, United States; Undisclosed, United States

This work investigates how the aging of lithium-ion batteries is influenced by several less well-known properties of different vehicle drive profiles. It is demonstrated that the RMS current value is a statistically significant aging factor for the case of dynamic drive profiles, extending the results of previous work that focused on steady-state discharge current waveforms. In addition, a quantitative analysis procedure is developed to facilitate the separation of aging factors and to analyze their individual and mutual effects. Strong statistical evidence is presented to support the importance of the interaction between the RMS current value and the battery discharge temperature on aging characteristics. The impact of these outcomes on designing battery systems that include provisions for reducing the AC content of the battery current as a function of the battery operating temperature are discussed.

**P4302***Performance Degradation of Thermal Parameters during Cycle Ageing of NMC-based Lithium Ion Battery Cells [#982]*  
Tiberiu Stanciu, Daniel Stroe, Maciej Swierczynski, Nerea Nieto, Jon Gastelurrutia Roteta, Jean-Marc Timmermans and Remus Teodorescu   
, Aalborg University, Denmark; IK4-Ikerlan, Spain; Vrije Universiteit Brussel, Belgium

The accelerated demand for electrifying the transportation sector, coupled with the continuous improvement of rechargeable batteries characteristics, have made modern high-energy Lithium-ion (Li-ion) batteries the standard choice for hybrid and electric vehicles (EVs). Consequently, Li-ion batteries electrochemical and thermal characteristics are very important topics, putting them at the forefront of the research. Along with the electrical performance of Li-ion battery cells, their thermal behavior needs to be accurately predicted during operation and over the lifespan of the application as well, since the thermal management of the battery is crucial for the safety of the EV driver. Moreover, the thermal management system can significantly lower the degradation rate of the battery pack and thus reduce costs. In this paper, the thermal characterization of a commercially available Nickel-Manganese-Cobalt (NMC) based Li-ion battery cell was performed under different operating conditions: state-of-charge (SOC) levels, charge-discharge current rates and operating temperatures. Moreover, by carrying out accelerated cycle ageing tests on a total of nine NMC-based Li-ion battery cells, the effect of ageing on the most important thermal parameters was investigated.

**P4303***Investigation of Current Sharing and Heat Dissipation in Parallel-Connected Lithium-Ion Battery Packs [#1049]*  
Yichao Zhang, Ruxiu Zhao, Jacob Dubie, Larry Juang and Thomas Jahns   
, University of Wisconsin Madison, United States; Undisclosed, United States

This paper adopts a circuit model with temperature-dependent parameter values to investigate the current unbalance risk in parallel-connected lithium-ion (Li-ion) battery cells and uses this circuit model to calculate heat dissipation.

**P4304***A Cooperative Charging Strategy for Onboard Supercapacitors of Catenary-Free Trams [#1165]*  
Heng Li, Jun Peng, Rong Zhou, Zhihui Wu, Zhiwu Huang and Jianping Pan   
, Central South University, China; University of Victoria, Canada

In this paper, a cooperative charging strategy is proposed for onboard supercapacitors of catenary-free trams. The multi-module charging system consists of n buck converters connected in parallel. The parallel-input parallel-output (PIPO) charging system is modeled mathematically using the averaging method. A cooperative constant-current charging control strategy is designed using the leader-follower consensus approach, where the virtual leader represents the desired charging current for each charging module with a warm-start mechanism. The cooperative charging approach provides dual benefits of both excellent dynamic performance and good reliability. Simulation and experiment results are provided to illustrate the effectiveness of the design

**P4305***A High Frequency Zero-Voltage-Transition (ZVT) Synchronous Buck Converter for Automotive Applications [#1123]*  
Chenhao Nan and Raja Ayyanar   
, Arizona State University, United States

Automotive applications require a wide input voltage range (4.5 V to 42 V) and high frequency operation for point-of-load low power (5 W-25 W) converters. The conventional buck converter, currently being used for this application, is simple and cost effective but it is less efficient at high switching frequency (>MHz) and noisy due to its hard-switching operation. A zero-voltage-transition (ZVT) synchronous buck converter is proposed in this paper, which features ZVS for main switches, ZCS and low voltage rating for auxiliary switches. The operating principles including ZVS/ZCS mechanism, and detailed design considerations are presented. Experimental results from a 1 MHz prototype confirm its superior performance for low power automotive applications.

**P4306***The Dual-Channel Magnetically Integrated Chargers for Plug-in Electric Vehicles [#1292]*  
Bochen Liu, Zheng Wang, Yue Zhang, Ming Cheng and Liang Xu   
, Southeast University, China; Aviation Key Laboratory, China

In this paper, a dual-channel isolated three-phase magnetically integrated chargers (MICs) are presented for plug-in electric vehicles. The key is to apply and operate two interleaved power charging circuits, each of which is composed of one dual-active-bridge (DAB) isolated converter and one three-phase grid inverter. The proposed configuration not only offers isolated charging but also provides modular design and operation for each channel, which are useful for high-power applications in fast charging. The interleaved operation and the phase-shifted carriers enable low current ripple on battery side and better harmonic performance on grid side. Furthermore, chaotic modulation has been applied to reduce the distinct switching harmonics in spectrum, which will facilitate improving the conducted electromagnetic compatibility (EMC). The detailed design of modulation strategy and control scheme are described in this paper. Experimental results have been presented for a 1-kW laboratory prototype to verify the validity of the proposed configuration and schemes.

**P4307***Power-Line Impedance Modeling of Tractor-Trailer System [#1660]*  
Iftekhar Hasan, Aparna Saha, Mohamad Abd Elmutalab, Ibrahem Amr, Philip Kasper, Yilmaz Sozer and Marv Hamdan   
, University of Akron, United States; Bendix CVS, United States

This paper focuses on the channel characterization and modeling for power line communication (PLC) inside a Tractor-Trailer system. Understanding the behavior of the power line in tractor-trailer system at PLC frequency bands is quintessential for designing the PLC system to achieve desired performance. In this paper, s-domain impedance signatures for the tractor, trailer, dolly, harness and electronic control unit (ECU) has been developed by making impedance measurements of the system under different loading scenarios. The transfer function model predicting the PLC channel impedance under the given frequency band, shows good agreement between the estimated and measured data on a tractor-trailer system test bed platform

Poster Session: Power Converter Topologies

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Pradeep S. Shenoy, Leon M Tolbert

**P4501***An Interleaved 1-to-6 Step-Up Resonant Switched-Capacitor Converter Utilizing Split-Phase Control [#1286]*  
Andrew Stillwell, Derek Heeger, Christopher Meyer, Sarah Bedair and Robert Pilawa-Podgurski   
, University of Illinois at Urbana-Champaign, United States; Army Research Laboratory, United States

Hybrid and resonant switched-capacitor (SC) converters have the potential to achieve higher power densities than conventional dc-dc converters. This work presents an interleaved, 20 V to 120 V, resonant SC converter which could be used in applications that benefit from high power density and efficiency. The resonant topology of this SC converter enables a compact and efficient design that minimizes losses. We use a new split-phase control scheme that incorporates precisely timed additional transition states to increase the converter efficiency. A two-phase interleaved design increases the output power and simultaneously decreases the output ripple through harmonic cancellation. In addition to experimental evaluation of a 95.7% efficient, GaN-based prototype of this interleaved converter, an analysis of current sharing between interleaved phases is performed.

**P4502***Boost Composite Converter Design Based On Drive Cycle Weighted Losses in Electric Vehicle Powertrain Applications [#1409]*  
Hyeokjin Kim, Hua Chen, Robert Erickson and Maksimovic Dragan   
, University of Colorado at Boulder, United States

A weighted design optimization is introduced to minimize total loss of electric vehicle drivetrain power electronics over EPA standard drive cycles. It is shown that the net loss of the conventional boost converter can be reduced by a factor of 1.5 with this approach, while computational effort is reduced by three orders of magnitude. Even larger efficiency improvements are achieved by optimized boost composite converters: losses are reduced by factors of 4.5, 2.9, and 4.3 for US06, UDDS, and HWFET driving cycles, respectively. These design optimization results are experimentally verified with a 30 kW laboratory prototype boost composite converter, which demonstrates 98.4% average efficiency over the US06 driving cycle.

**P4503***Design of a Four-Phase Interleaved Boost Circuit with Closed-Coupled Inductors [#1422]*  
Daigoro Ebisumoto, Masataka Ishihara, Shota Kimura, Wilmar Martinez, Noah Mostafa, Masayoshi Yamamoto and Jun Imaoka   
, Shimane University, Japan; Shimane University, Colombia; Kyushu University, Japan

In this paper, a novel magnetic structure suitable for boost converters is proposed. Multi-phase interleaved method using coupled-inductor has gained attention in electric powertrains for electric, hybrid and fuel cell vehicles in order to achieve high power density. In fact, a four-phase boost converter using coupled inductor is used in the drive system of the Honda CLARITY. In particular, magnetic coupling method is used in coupled inductors, Loosely-Coupled Inductors (LCI) and Closed-Coupled Inductors (CCI). This study is focused on these methods, especially using the CCI. This paper presents a design method of a closed-coupled inductors using generic cores for a four-phase interleaved boost converter. In addition a comparison between the proposed topology with other conventional non- coupled methods is carried out. Furthermore, the evaluation of miniaturization is studied. As a result, the proposed method can achieve a huge reduction in the core volume and mass.

**P4504***Hybrid DC-DC Buck Converter with Active Switched Capacitor Cell and Low Voltage Gain [#54]*  
Mauricio Dalla Vecchia and Telles Lazzarin   
, Federal University of Santa Catarina - UFSC, Brazil

This paper proposes a novel dc-dc buck converter that is composed by an active switched capacitor cell and a conventional buck converter. The proposed converter is named as hybrid buck converter and it presents static gain from 0 to 0.5, maintaining the typical linear characteristics of the buck converter and it reduces the voltage stress on the power components. A theoretical steady state analysis to obtain the steady values of all capacitor voltages and the inductor current are presented. A generalization of the switched capacitor cell is also proposed to show the extensive applicability of this structure to dc-dc high step-down voltage ranges. Simulation and experimental results are reported herein to corroborate the proposed structure and the theoretical analysis. An efficiency result is also reported in this paper for the rated power. The prototype specification designed was: 1 kW, 600 V in input voltage and 150 V in output voltage.

**P4505***High Gain Resonant Boost Converter For PV Micro- Converter System [#1582]*  
Sachin Jain, Swami Satish Betha and Jih-Sheng (Jason) Lai   
, NIT Warangal, India; Virginia Polytechnic Institute, United States

This paper presents an isolated high-gain topology which employs resonant boost converter with coupled inductor or boost transformer for the Photovoltaic (PV) micro-converter system. The given configuration has the features of resonant soft switching, galvanic isolation, high gain and low switching losses. The proposed system uses LC series resonant tank circuit and had resonant operation both during turn-ON and turn-OFF. Further, the system operates near resonant frequency which minimizes the circulating or reactive current requirement in the resonant circuit. The proposed system operates in DCM mode with small losses during turn-OFF for the boost switch. Also, the proposed system has a wide operating voltage range for the PV source compared to existing solutions. In total, the given configuration has the benefits of coupled inductor technique, voltage doubler technique, resonant switching and galvanic isolation. Details of working principle, modes of operation and analysis with simulation and hardware results are presented in the manuscript.

**P4506***Design of Two-Switch Flyback Power Supply Using 1.7 kV SiC Devices for Ultra-Wide Input-Voltage Range Applications [#1686]*  
Gabriele Rizzoli, Jun Wang, Zhiyu Shen, Rolando Burgos, Dushan Boroyevich and Luca Zarri   
, University of Bologna, Italy; CPES-Virginia Tech, United States

This paper presents the design and evaluation of a two-switch flyback power supply with ultra-wide input voltage range, fed from the floating dc bus of power electronics building blocks in medium voltage modular multilevel converter applications. Rated at 80 W, 48 V output, and operating at 50 kHz, the proposed converter uses 1.7 kV SiC devices and a planar PCB-winding transformer to achieve a low-profile form factor. Experimental results are presented for verification and evaluation purposes.

**P4507***A Single-Stage Interleaved LLC PFC Converter [#1223]*  
Raed Saasaa, Wilson Eberle and Mohammed Agamy   
, The University of British Columbia, Canada; GE Global Research Center, United States

This paper presents a novel single-stage AC/DC converter that can achieve high power factor with reduced switching losses for semiconductor devices. The topology is derived by integrating the interleaved boost-type PFC and full bridge LLC resonant converters. Due to interleaving at the input, the converter exhibits less input current ripple compared to the existing single stage topologies. Therefore, it is suitable for applications up to approximately 500 W. A detailed analysis of the operation modes is presented. Also, a 350-W prototype is designed at (120 V) input AC voltage to verify the effectiveness of the topology. Applications requiring DC voltages vary widely, from low power, such as LED lighting, to high power, as in industrial motor drives and battery chargers. Accordingly, a unified power architecture for all applications is not practical for efficiency, size and cost optimization. The use of LED lighting system became popular due to its many advantages. The new outdoor applications such as street and flood lighting require high power (i.e. >200 W) in contrast to the low power existing LED drivers. Generally, the conventional architecture of AC/DC converters consists of two main stages; the first is current-shaping stage to improve PF and the second is to provide isolation and tight regulation over the output voltage The proposed single-stage topology integrates the interleaved boost and resonant LLC converters. Consequently, it can operate at higher power due to the use of interleaving, which significantly reduces the current ripple. Moreover, all semiconductor devices have soft switching transitions: ZVS for MOSFETs and ZCS for diodes, improving the overall efficiency. The converter achieves a peak efficiency equal to 92.3%, and high PF (0.997) at full load and nominal input voltage.

**P4508***Medium Voltage AC-DC Rectifier for Solid State Transformer (SST) Based on an Improved Rectifier Topology [#1337]*  
Qianlai Zhu, Li Wang, Xijun Ni, Liqi Zhang, Wensong Yu and Alex Q. Huang   
, North Carolina State University, United States; Nanjing Institute of Technology, China

The implementation of a novel bidirectional medium voltage AC-DC converter based on 10kV SiC MOSFET is presented in this paper. The improved topology allows the removal of the reverse blocking silicon diode in medium voltage SiC MOSFET module. Shoot-through problems and avalanche of the integrated silicon diode in traditional medium voltage bridge-type AC-DC converters are solved, allowing zero dead-time operation with no current flowing through the body diode. The number of parasitic capacitors at each swing point are reduced by half, greatly reducing the dominant turn on losses caused by these capacitors. A unique customized four-in-one 10kV SiC MOSFET/JBS diode power module with high voltage isolation capability is developed and tested, which reduces parasitic parameters and simplifies converter complexity. Section based winding method is further used to reduce the inductor parasitic capacitance by 40%, helping to reduce the dominant turn-on losses by 13%. Anti-windup and feed forward control are implemented to achieve better performance. Soft start combining with a high voltage relay and fuse are used to limit the inrush current and overshoot voltage during the start- up process. Delta-sigma based fiber optical high voltage sensor is designed and implemented to achieve higher than 10kV voltage sensing capability.

**P4509***Microcontroller-Based MHz Totem-Pole PFC with Critical Mode Control [#1429]*  
Zhengrong Huang, Zhengyang Liu, Qiang Li and Fred Lee   
, CPES, Virginia Tech, United States

This paper focuses on how to implement critical conduction mode (CRM) control for GaN-based MHz totem-pole PFC with a commercial low-cost microcontroller (MCU), including basic CRM operation, programmed on-time control for achieving low current THD, off-time extension for achieving ZVS for whole line cycle operation, and two-phase interleaving control for input current ripple cancellation and EMI filter size reduction. A novel but simple improvement of zero-current-detection (ZCD) based CRM control method is proposed to solve signal processing de-lay issue to realize CRM operation for MHz totem-pole PFC. A simple but very accurate on-time calculation method is also pro-posed for implementing programmed on-time control at MHz high frequency. The result of aforementioned control function integration and implementation is demonstrated on a 1.2kW GaN-based MHz totem-pole PFC prototype.

**P4510***Three-Phase Isolated DCM SEPIC Converter for High Voltage Applications [#585]*  
Gabriel Tibola, Erik Lemmen and Ivo Barbi   
, Eindhoven University of Technology, Netherlands; Federal University of Santa Catarina, Brazil

The analysis of an isolated single-stage three-phase ac-dc converter with high power factor, based on the modularity of dc-dc SEPIC converters operating in discontinuous conduction mode is presented in this paper. The ac input is star- connected while the output of the modules are series connected. Doing so, the converter can provide a high step-up ratio and, consequently, besides high output voltage, a natural unity power factor is achieved. A review of the PFC three- phase SEPIC converters is performed, and discussion regarding to the advantages and drawbacks of the proposed connection when compared to previous solutions is made. Additionally, experimental results for a 4 kW, 380 V line-to-line input voltage and 1200 V output voltage laboratory prototype are presented in order to validate the analysis.

**P4511***Single Phase Precharge Control Method for Active Front End Rectifier [#1595]*  
Lixiang Wei, Zeljko Jankovic, Yogesh Patel and Jiangang Hu   
, Rockwell Automation, United States

Active front end rectifiers (AFE) are widely used in various industrial area applications. In these types of systems, AC pre-charge circuit, output LCL filter and power module switches are the three most critical power segments. AC pre-charge circuit design is often related to an overall high component volume and cost. Many manufacturers adopt mechanical contactors or breakers between the utility connection point and the rectifier in order to ensure a smooth pre-charge of the DC bus capacitors. Since these mechanical components are typically associated with lower reliability and increased size, the power density and lifetime of the whole system gets affected significantly. This paper proposes a simple solid state pre-charge circuit for AFE rectifiers. Solid state pre-charge circuit offers a fairly simple control while reducing the inrush current for both LCL filter and DC bus capacitors. This method also demonstrates the following advantages: 1) increased lifetime, 2) smaller foot print 3) lower cost. Basic operating theory and circuit analysis along with simulation and experimental results are presented in the paper to demonstrate the effectiveness of the proposed method

**P4512***Adaptive Controlled-type Zero-voltage-switching Inverters with Bandwidth Limitation [#927]*  
Dehua Zhang, Jiali Wang and Zhengyu Lv   
, Zhejiang University, China

A high performance inverter requires high power density, high reliability, and low cost. An adaptive controlled-type soft-switching technique achieves high efficiency and requires no additional power devices or magnetic components but with inherent frequency variation. Based on the general full-bridge inverter topology, the change in frequency under various modulation modes and load properties are studied. In order to narrow the frequency variation range, a continuous current mode (CCM) with bandwidth limitation control scheme is proposed. An adaptive controlled-type zero-voltage switching inverter with analog- digital control platform is designed and built to verify the proposed control scheme. The experimental results show that the proposed current modulation scheme has fixed switching frequency.

**P4513***Half Bridge NPC Inverter and Its Three Phase Application with Constant Common Mode Voltage [#1291]*  
Liwei Zhou, Feng Gao, Chongsheng Jia and Tao Xu   
, Shandong University, China; State Grid Jinan Li Cheng Power Supply Company, China

In the transformerless grid connected photovoltaic system, the inverter is the main component. In order to improve the efficiency of the inversion system, several topologies have been applied, among which three level NPC inverter is a kind of popular application. Because the three level NPC inverter has the advantages of low switching losses, good common mode behavior and the small output distortion. This paper proposed a kind of novel three level half bridge NPC inverter which only applies four switches with a constant common mode voltage. Compared to the traditional half bridge NPC inverter, the proposed topology consumes less devices and has a lower conducting losses. The common mode model of the novel topology is analyzed which has verified the good common mode behavior. The three phase extended topology of the proposed inverter is also introduced with a novel modulation strategy. With the proposed modulation strategy, the three phase inverter has a constant common mode voltage. Finally, the simulation and experimental results illustrated the theoretical findings.

**P4514***Interleaved Auxiliary Resonant Snubber for High-Power, High-Density Applications [#1460]*  
Rachael Born, Lanhua Zhang, Yu Wei, Qingqing Ma and Jason (Jih-Sheng) Lai   
, Virginia Tech Future Energy Electronics Center, United States

Power density has become increasingly important for applications where weight and space are limited. New wide-bandgap (WBG) devices, combined with softswitching, now allow inverters to shrink in size by pushing to higher switching frequencies while maintaining efficiency. This paper proposes a novel interleaved auxiliary resonant snubber for high-frequency soft-switching to reduce volume while maintaining efficiency. The design of an auxiliary resonant snubber is discussed; this allows the main GaN MOSFETs to achieve zero voltage switching (ZVS). The auxiliary switches and SiC diodes achieve zero current switching (ZCS). While soft-switching minimizes switching loss, conduction loss is simultaneously reduced for high-power applications by interleaving two high frequency legs.

**P4515***Three-Phase Four-Wire Inverters Based on Cascaded Three-Phase Converters with Four and Three Legs [#1027]*  
Joao Paulo Ramos Agra Mello, Cursino Bradao Jacobina and Mauricio Beltrao Rossiter Correa   
, Universidade Federal de Campina Grande, Brazil

This paper presents three-phase converter topologies for four-wire systems. The converters are series connected by three-phase transformers with accessible neutral. They possess a common dc-link, which is the power supply of the system, and two or more converters, where one of them is connected directly to the ac system, and the others cascaded through three-phase transformers. The three-phase transformers have turn ratios that are calculated in order to maximize the number of levels produced by the inverters. The Level-Shifted Pulse Width Modulation technique is developed for two and three cascaded converters, and a control system is used to set the electrical grid currents on desired values. Simulation and experimental results are exposed for configurations with two cascaded converters, each one with either three or four legs.

**P4516***Optimal Switching Counts Modulation of H7 Current Source Inverter [#1270]*  
Weiqi Wang, Feng Gao, Lei Zhang, Chen Mengxing and Liwei Zhou   
, Shandong University, China; Shandong Electric Power Research Institute, China

The current source inverter (CSI) has some application restrictions, especially for the power efficiency problem. The H7 current source inverter is a promising topology since it provides a shunt-connected switching path and significantly reduce the power dissipation. This paper reviews the already published H7 CSI configuration character with its modulation strategy in theory and proposes an optimal modulation scheme which has the minimized hard switching counts. In addition, the grid-tied operational principle has been discussed. The proposed modulation strategy could reduce the working power dissipation, simplify the configuration of the shunt-connected switch, and meanwhile guarantee the zero current switching ability for the rear-end CSI circuitry. The switching counts and hardware cost are compared between the different modulation schemes to prove the superiority of the proposed optimal switching counts modulation strategy. The simulation and experimental results verified the theoretical findings.

**P4517***Cuk-Based Universal Converters in Discontinuous Conduction Mode of Operation [#1471]*  
Mahshid Amirabadi   
, Northeastern University, United States

This paper introduces an open-loop control scheme for Cuk-based universal converters that have recently been proposed by the author. Cuk-based universal converters extend the principles of the operation a dc-dc Cuk converter to systems with single- phase or multi-phase ac sources and/or loads. These power converters can provide galvanic isolation by adding a single-phase high frequency transformer to the link. This eliminates the need for low frequency transformers that have large volume and weight. Being single-stage, the Cuk-based universal converters do not require decoupling components, and a small capacitor is used for transferring the power from input towards output. This eliminates the need for large electrolytic capacitors that have high failure rates. In prior works, a closed-loop control system was used for the Cuk-based universal converters. These converters were controlled such that they always operate at the boundary of continuous and discontinuous conduction modes, which leads to a variable switching frequency and a large voltage ripple across the link capacitor. The closed-loop operation along with variable switching frequency result in a complex control algorithm, which can limit the maximum switching frequency of the converter. This paper proposes an open-loop control scheme that allows the converter operate in discontinuous conduction mode and with a fixed switching frequency. Implementation of the proposed control scheme is simpler than the closed-loop control method. This paper presents details of the proposed method and evaluates its effectiveness.

**P4518***Neutral Points Voltage Balancing Control of a Four-level pi-type Converter [#1084]*  
Bosen Jin and Xibo Yuan   
, University of Bristol, United Kingdom

In this paper, a carrier based modulation method with optimal zero sequence signal injection has been introduced to modulate a four level pi type converter as well as regulate its DC link neutral points voltages. The two neutral points voltages can be well controlled with a back to back configuration even under high modulation index and high power factor. A back to back experimental system has been built and tests under 300V have validated this control strategy.

**P4519***A Novel Three-Phase Multilevel Diode-Clamped Inverter Topology with Reduced Device Count [#1369]*  
Aparna Saha, Ali Elrayyah and Yilmaz Sozer   
, University of Akron, United States; Qatar Environmental and Energy Research Inst, Qatar

This paper presents a novel configuration of three-phase multilevel diode-clamped inverter (DCI) with reduced part count. In the proposed topology, three-phase multilevel output voltage is generated by employing only two inverter phase legs and the third phase is sharing the unused switches of these two legs depending on the line current flow direction. The structure allows synthesizing multilevel voltage waveform with reduced number of power electronic components: diodes, power semi-conductor switches and gate driver circuits compared to classical topologies. Total savings on the power device count increases proportionally for higher output voltage level DCIs. Reducing the counts on the power electronic devices result in decreased complexity and overall system cost for the inverter. The compatibility of developed general space vector modulation (SVM) technique with new multilevel DCI arrangement; make the control scheme simpler and easily implementable. The simulation results confirm the feasibility of the proposed configuration in comparison with the conventional multilevel DCI topology.

**P4520***Maximum Boost Space Vector Modulated Three-Phase Three-Level Neutral-Point-Clamped Quasi-Z-Source Inverter [#1040]*  
Prasanth Sundararajan, Mohamed Sathik Mohamed Halick, Aaron Alexander Ayu, Tan Chuan Seng and Suresh Kumar K. S.   
, Nanyang Technological University, Singapore; National Institute of Technology, India

Z-source inverter is a power electronic converter with potential applications in areas like renewable energy, electric vehicles, etc. because unlike traditional inverters, it can provide a boost in output voltage without any additional DC-DC boost converter stage in between the DC source and inverter. This feature is particularly useful if the input DC source is of low voltage like battery or of fluctuating nature as in case of PV panels. The elimination of need for DC-DC converter stage in an inverter system increases the overall reliability of the system and also increases the overall efficiency by the elimination of DC-DC converter stage losses. In this paper, a maximum boost space vector modulation strategy which gives maximum gain for three-phase three-level quasi-Z-source inverter (QZSI) is proposed. The proposed algorithm has been verified by both simulation and experimental results.

Poster Session: Control, Modelling and Optimization of Power Converters

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Pericle Zanchetta, Luca Solero

**P4701***High Dynamic and Static Performance FCS-MPC Strategy for Static Power Converters [#1156]*  
Rodrigo Mendez, Daniel Sbarbaro and Jose Espinoza   
, Concepcion University, Chile

This paper proposes an improved Finite Control Set Model Predictive Control (FCS-MPC) strategy to control static power converters that overcomes the parameter sensitivity of the conventional strategy. The parameters error can be due to both a poor estimation and their time variant behavior, as the grid parameters in grid connected static power converters. Contrary to the standard FCS-MPC approach that tracks a system output reference, the proposed scheme is based on a system input reference tracking that can be obtained from a state-feedback. In the proposed scheme, output system integrators are added to modify the dynamic performance and ensure zero steady-state error under parameters errors. This approach overcomes one important disadvantage that presents the conventional FCS-MPC strategy which is the dependence of a model with accurate parameters to avoid performance degradation. The results verify the correct performance in both with or without parameters errors

**P4702***New Logic-Form-Equation Based Active Voltage Control for Four-Level Flying Capacitor Multicell (FCM) Converter [#1225]*  
Arash Khoshkbar Sadigh, Vahid Dargahi and Keith Corzine   
, Extron Electronics, United States; Clemson University, United States

This paper presents a new active capacitor voltage balancing method for flying capacitor multicell (FCM) converter which is implemented using logic-form equations. The proposed active capacitor voltage balancing technique, measures output current and FC voltages to generate switching states to produce the required output voltage level as well as balance FC voltages at their reference values. Output voltage of the FCM converter with the proposed active voltage balancing method can be modulated with any kind of the pulse-width-modulation method such as phase-shifted-carrier PWM (PSC-PWM) or level-shifted-carrier PWM (LSC-PWM). Advantage of the proposed active voltage balancing method is its simplicity without any complex computation burden. Simulation results of a three-cell four-level FCM converter are presented to verify performance of the proposed active capacitor voltage balancing method.

**P4703***Experimental Evaluations of Thinned-Out and PDM Controlled Class-E Rectifier [#1307]*  
Akane Iwasaki, Tomoharu Nagashima and Hiroo Sekiya   
, Chiba University, Japan

This paper presents the design of the closed-loop thinned-out controlled class-E rectifier. It is possible to realize both thinned-out control and the PDM one at the same control-circuit topology. In addition, fine output-voltage controls are possible because the control circuit can make a thinned-out signal at any thinned-out ratio. For evaluating the proposed class-E rectifier, the resonant dc/dc converter with the class-DE inverter and the proposed class-E rectifier is designed and implemented. The control characteristics of the resonant converter were measured for load and input- voltage variations. It is seen from the experimental results that the thinned-out control provides higher efficiency than the PDM control. In addition, the power spectrum of the switch voltages suggested that the cutoff frequency of the low-pass filter for thinned-out control can be higher than those for the PDM control, which contributes circuit-volume reduction.

**P4704***Variable Slope External Ramp to Improve the Transient Performance in Constant On-Time Current Mode Control [#1632]*  
Syed Bari, Brian Cheng, Qiang Li and Fred Lee   
, CPES, Virginia Tech, United States; Texas Instruments, United States

These days, constant on-time current mode (COTCM) control schemes are widely used in the industry VR controllers for its light load efficiency and higher BW design with simpler compensation requirement. In COTCM control, external ramp is required to be added for jittering reduction to improve the noise performance of the controller. But unfortunately, with the increment of external ramp value, although the jittering in the system gets better, transient performance becomes worse. For this reasons, from transient point of view, it is very challenging to use large external ramp in the system to improve the noise performance. In this paper, a novel method is proposed to modify the external ramp at the transient instant to improve the transient response by increasing the slope of the ramp, and thus allows the control to use the large external ramp for noise performance improvement and enjoys the fast transient response at the same time.

**P4705***PWM Methods for High Frequency Voltage Link Inverter Commutation [#1641]*  
Minjeong Kim, Mostafa Mosa and Robert S. Balog   
, Texas A and M University, United States

This paper presents two new pulse-width modulation (PWM) methods for a high frequency ac-link (HFlink) inverter commutation which uses a form of four- step switching scheme for safe commutation. A HF-link inverter topology enables galvanic isolation and voltage step-up, with a reduced-size transformer, but eliminates the secondary-side rectification so it has less power conversion stages than other inverter topologies. However, converting the HF-link voltage to the desirable inverter output voltage adds complexity to the control of the circuits because it is a form of ac-ac converter with both the inverter bridge input and output voltages timevarying. The voltage- reference four-step switching technique was previously presented as a safe commutation technique for the ac-ac converter with bidirectional switches. The method provided safe commutation without detailed information of the exact output current zero-cross and without needing lossy snubber circuits. However, it assumed that the input voltage polarity remained constant during the current commutation interval. This paper proposes methods to overcome the limitation of the previous method to ensure so call safecommutation even when the HF-link voltage is changing polarity and that can be implemented by modification of conventional triangular carrier PWM methods. Therefore, the four-step switching scheme can be safely applied to the HF-link inverter. Simulations of the proposed new PWM methods are conducted using Simulink and Plexim software to demonstrate the concepts. The proposed PWM methods were experimentally verified using the dSpace 1007 HIL platform.

**P4706***Switching Pattern of a Modular Voltage Balancing Circuit for Battery Cells [#1681]*  
Atrin Tavakoli, Sayed Ali Khajehoddin and John Salmon   
, University of Alberta, Canada

Switching patterns are described for balancing the voltages of series connected Li-ion polymer batteries using non-dissipative cascaded modular power electronics. A balancing circuit is connected to two battery cells and consists of an asymmetrical half-bridge and a high frequency transformer. This reduces the number of switches and diodes to an average of one per battery. A balancing circuit or module can balance the voltage of two batteries by using two magnetically coupled windings connected to the centre tap of the two batteries: intra-bridge voltage balancing. Each module is coupled to adjacent modules by connecting transformer windings. Two fundamental control methods are described for transferring electrical charge between the batteries in adjacent modules: inter-bridge voltage balancing. Both control methods, "2-switch flyback control" and "phase-shifted control", assume that each module determines its own switching pattern by monitoring the dc voltages in each of its adjacent modules. The relative merits of both controllers are described. Simulated and experimental results are presented for both controllers to validate the charge transfer methods used.

**P4707***Steady State Impedance Estimation of a Weak Grid to Assist Optimal Current Injection for Minimal Power Losses [#413]*  
Akrama Khan, Azeem Khan and Michel Malengret   
, University Of Cape town, South Africa; University of Cape Town, South Africa

Nowadays, latest advancements in power electronics have devised new ways to optimise power systems by reducing power losses. These developments provide convenience for private power producers to harness renewable energy and allow injection of optimized reactive currents to compensate for the reactive power drawn from the grid. This paper presents the development of an efficient laboratory based system that can monitor a transmission line, sense changes in the load and redistribute the optimal currents in a manner that ensures minimized power (I2R) losses at the point of common coupling (PCC). A method is discussed and implemented to calculate and feed the required optimal currents into the grid. This method depends on the measurement of dynamic parameters of the electrical grid which are calculated by applying a steady state impedance estimation technique. Once parameters are obtained, the aforementioned method is applied which allows the flow of optimal currents in the system. National Instruments (NI) PXI controller with built-in FPGA module is used for experimental investigation which demonstrates capability of the discussed technique to produce the required results.

**P4708***A Single-phase Unified Power Quality Conditioner with An Enhanced Repetitive Controller [#916]*  
Dang-Minh Phan, Cong-Long Nguyen and Hong-Hee Lee   
, University of Ulsan, Korea (South)

This paper proposes a robust and flexible control strategy for a single-phase unified power quality conditioner (S-UPQC) to solve the power quality problem due to the distorted input supply voltage and the nonlinear load. In order to enhance the performance of the series and shunt active power filters (APFs) in S-UPQC, an advanced current and voltage control schemes are introduced based on the modified repetitive controller (RCs) connected with a proportional-integral (PI) controller. Unlike the conventional control scheme for the series and shunt APFs, the proposed scheme is implemented without any harmonic extractor. Furthermore, the dynamic performance is improved significantly due to the reduced delay time of the RC, and the computation time is also reduced. The effectiveness of the proposed control schemes for the S-UPQC is validated through simulation.

**P4709***Single-Phase Universal Active Power Filter Based on AC/AC Converters [#1176]*  
Phelipe Leal Serafim Rodrigues, Cursino Brandao Jacobina and Mauricio Beltrao de Rossiter Correa   
, DEE UFCG, Brazil

This paper presents four single-phase universal active power filters (UAPF) topologies with 4, 5, 6 and 7 legs. The proposed systems are based on AC/AC converters with two transformers. They are suitable to improve the harmonic distortion in the grid currents and a voltage compensation. The filter uses a combination of two series filters and one shunt filter sharing a single DC-link. The proposed active filters are capable of generating input and output voltages with low harmonic content and consists of low-power switches. The complete control system, including the PWM techniques based on vector approaches, is developed. Simulation and experimental results are shown for validation purposes.

**P4710***Circulating Resonant Current Between Integrated Half-Bridge Modules with Capacitor for Inverter Circuit Using SiC-MOSFET [#874]*  
Takashi Hirao, Keiji Wada and Toshihisa Shimizu   
, Tokyo Metropolitan University, Japan

A design for the inverter circuit configuration of integrated half-bridge modules with a focus on the circulating resonant current is clarified in this paper. Although this configuration has the advantages of small DC-side stray inductance, an analysis of the equivalent circuit suggests that a DC-side capacitor current increases depending on the relationship between the resonant and switching frequencies. This fact will lead to an increase in the capacitor volume. The capacitor current was experimentally investigated at switching frequencies up to 100\,kHz using a SiC-MOSFET. The experimental results demonstrated that the resonant current was remarkable when the resonant frequency was close to either the fundamental or the third harmonics of the switching frequency. By the proposed design, the increase in the capacitor current can be avoided.

**P4711***Computationally Efficient Event-Based Simulation of Switched Power Systems and AC Machinery [#979]*  
Christopher Wolf and Michael Degner   
, Ford Motor Company, United States

Switched power systems are inherently difficult to simulate, due to the significant sensitivity of the simulation algorithm to the timing of the switching events as well as the potentially complex dynamics of the components. Numerical simulation techniques, while flexible, are not well suited for large time scale simulation of such systems. Methods for increasing the accuracy of numerical simulation techniques increase the computational complexity of the solution, resulting in an obstacle for adoption into time-sensitive applications such as model-based design optimization and hardware-in-the-loop simulation. This paper presents a method and development framework for a computationally efficient method for analyzing the behavior of switched power systems via piece-wise analytical solutions to differential equations. Enhancements of the method to expand the utility are also presented.

**P4712***Design Optimisation and Trade-offs in Multi-kW DC-DC Converters [#1047]*  
James Scoltock, Gerardo Calderon-Lopez, Yiren Wang and Andrew Forsyth   
, University of Manchester, United Kingdom

This work investigates design optimisation and design trade-offs for multi-kW DC-DC Interleaved Boost Converters (IBC). A general optimisation procedure for weight minimisation is presented, and the trade-offs between the key design variables (e.g. switching frequency, topology) and performance metrics (e.g. power density, efficiency) are explored. It is shown that the optimal selection of components, switching frequency, and topology are heavily dependent on operating specifications such as voltage ratio, output voltage, and output power. With the device and component technologies considered, the single-phase boost converter is shown to be superior to the interleaved topologies in terms of power density for lower power, lower voltage specifications, whilst for higher-power specifications, interleaved designs are preferable. Comparison between an optimised design and an existing prototype for a 220 V - 600 V, 40 kW specification, further illustrates the potential weight reduction that is afforded through design optimisation, with the optimised design predicting a reduction in component weight of around 33%.

**P4713***Switching frequency optimization for a Solid State Transformer with Energy Storage Capabilities [#1079]*  
Pablo Garcia, Sarah Saeed, Hannes Schneider, Angel Navarro-Rodriguez and Jorge Garcia   
, University of Oviedo, Spain; University of Stuttgart, Germany

This paper is focused on establishing a procedure for measuring the efficiency dependency on the switching frequency for a solid state transformer, being one of the ports connected to an energy storage device (Lithium-Ion battery). Multiple contributions for measuring the efficiency/losses for different power converter structures for energy storage applications can be found in the literature. However, there are few references which consider the effects of the high frequency model of the battery in the complete system performance. This research will obtain a parametric high frequency model of the battery cells, based on a vector fitting method in frequency domain. This model will be used for the estimation of the overall system losses. It will be demonstrated that the contribution of the battery losses, as well as its behavior as a function of the switching frequency, can significantly affect the selection of the converter's switching frequency.

**P4714***Lag-Free Terminal Voltage Sensing in Low-Pass Filtered PWM Converters [#1085]*  
Adam Shea and Thomas Jahns   
, University of Wisconsin - Madison, United States

Several high-performance control algorithms for ac machine drives and other applications require accurate knowledge of the instantaneous converter output voltages. The use of a simple low-pass filter to remove the PWM switching frequency harmonics from the AC voltage measurements introduces undesirable amplitude and phase lag errors into the voltage measurements. This work presents compensation functions that make it possible to compensate these measured filter output voltages for both amplitude and phase lag errors introduced by zero-order-hold samplers and two different types of PWM algorithms. The impact of the selected filter time constant and the required accuracy of the compensating equations relative to the ADC accuracy are also addressed, leading to identification of the optimal filter break frequency for maximum accuracy.

Poster Session: Electrical Machines

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Bruno Lequesne, Mohammad Islam

**P4901***Cogging Torque Minimization with Rotor Tooth Shaping in Axial Flux-Switching Permanent Magnet Machine [#1346]*  
Ju Hyung Kim, Yingjie Li, Emrah Cetin and Bulent Sarlioglu   
, University of Wisconsin-Madison, United States

This paper proposes a rotor tooth shaping method to reduce the cogging torque of an axial flux-switching permanent magnet machine. The rotor tooth is shaped in different configurations, including constant, trapezoidal, asymmetrical, extended, and square shapes. 3-D finite element analysis is performed to compare the proposed shapes of rotor tooth. Peak-to-peak cogging torque, fundamental flux linkage, loaded torque, and the total weight of teeth are compared using various rotor tooth angles. The simulation results show that overall minimum cogging torque is achieved by the extended shape of rotor tooth.

**P4902***A 3D Printed Fluid Filled Variable Elastance Electrostatic Machine Optimized with Conformal Mapping [#1525]*  
Baoyun Ge, Daniel Ludois and Ghule Aditya   
, University of Wisconsin -Madison, United States

Recently, fluid filled electrostatic machines have demonstrated specific and volumetric torque density that hold promise to be competitive with electromagnetic machines in niche applications. These demonstrations of variable elastance (dual of reluctance) machines were non-optimized from an electrostatics perspective as their geometry was heavily constrained due to manufacturability. Higher performance electromechanical power conversion for electrostatics requires optimal geometric design. This paper proposes a semi-analytical method incorporating conformal mapping techniques with finite element (FE) analysis to optimize a variable elastance electrostatic machine in a low speed direct drive applications. As a proof of concept, an optimized geometry was built using additive manufacturing, specifically stereolithographic 3D printing, to circumvent geometry constraints. By building the machine from plastic plated with conductor, it is lightweight with improved torque density. This manufacturing approach suggests that a machine can be injected molded or cast in a single step. Experimental results support both the design and manufacturing approaches and the resulting machine is benchmarked against previous work.

**P4903***Effects of External Field Orientation on Permanent Magnet Demagnetization [#1648]*  
Peng Peng, Han Xiong, Julia Zhang, Wanfeng Li, Franco Leonardi, Michael Degner, Chuanbing Rong, Feng Liang and Leyi Zhu   
, Oregon State University, United States; Ford Motor Company, United States

This paper investigates how the orientation of the applied demagnetizing magnetomotive force (MMF) affects the demagnetization behavior of Nd-Fe-B magnets that are widely used for permanent magnet synchronous machines (PMSMs). This work designs and builds a customized test fixture that can produce a magnetic field with varying orientation and intensity to demagnetize magnet samples. A computer-controlled 2D mapping device is used to record the flux density above the test samples. The measurement results are compared with the 3D finite element analysis (FEA) simulations. The understanding and insight obtained from this work will help the robust design of magnets for high power density PMSMs with improved capability of withstanding demagnetization during overcurrent faults.

**P4904***Analytical Approach for Determining Inductance Matrix, Harmonic Voltage and Torque Ripple of Slotted PM Motors [#919]*  
Kahyun Lee and Jung-Ik Ha   
, Seoul National University, Korea (South)

This paper proposes a novel approach for calculating position-dependent inductance matrix of slotted permanent magnet synchronous motors (PMSMs) and advanced analytical models for machine voltage and torque. In a real PM machine, the slotted structure of the stator and rotor causes unintended variations in air-gap permeance and magneto- motive force (MMF). The proposed approach analyzes the effects of these variations on air-gap flux and winding inductances. The calculated d-q inductance matrix contains harmonic and coupling components. In this paper, both voltage and torque models are modified to reflect the changes in inductance matrix. Some nonlinear terms due to structural saliency are additionally considered. The results of simulation with finite-element method (FEM) are presented to verify the validity of the proposed inductance, voltage and torque models.

**P4905***Cogging Torque Minimization in Transverse Flux Machines [#1312]*  
Tausif Husain, Iftekhar Hasan, Yilmaz Sozer, Iqbal Husain and Eduard Muljadi   
, University of Akron, United States; North Carolina State University, United States; National Renewable Energy Lab, United States

This paper presents the design considerations in cogging torque minimization in two types of transverse flux machines. The machines have a double stator-single rotor configuration with flux concentrating ferrite magnets. One of the machines has pole windings across each leg of an E-Core stator. Another machine has quasi-U-shaped stator cores and a ring winding. The flux in the stator back iron is transverse in both machines. Different methods of cogging torque minimization are investigated. Key methods of cogging torque minimization are identified and used as design variables for optimization using a design of experiments (DOE) based on the Taguchi method. A three-level DOE is performed to reach an optimum solution with minimum simulations. Finite element analysis is used to study the different effects. Two prototypes are being fabricated for experimental verification.

**P4906***Torque Ripple Reduction in a Flux-Switching Permanent Magnet Machine Targeted at Elevator Door Applications by Minimizing Space Harmonics [#1344]*  
Hongsik Hwang, Dongjae Kim, Jin Hur and Cheewoo Lee   
, Pusan National University, Korea (South); Incheon National University, Korea (South)

A flux-switching permanent magnet (FSPM) machine using ferrite magnet is proposed to replace the permanent magnet synchronous motors (PMSMs) in elevator doors. In order to improve both mechanical robustness and manufacturability, bridges around permanent magnet (PM) slots have been adopted in the C-shaped core of an FSPM machine. The optimization of the C-shaped stator is conducted, and its prototype has been built up for experimental validation. Back- electromotive force (EMF) is estimated to prove that simulated results are correct and reliable. Compared to a PMSM designed for elevator doors, the efficiency of an FSPM machine is significantly improved in spite of using ferrite PM that is utilized in the PMSM, but there is a disadvantage in torque ripple due to the interaction of harmonic components between back-EMF and magneto-motive force (MMF). However, most of researches on an FSPM machine have been focused on eliminating harmonic components of back-EMF. In this paper, the design process of an FSPM machine based on winding function theory will be given to diminish torque ripple by considering the harmonics of back-EMF and MMF in air gap.

**P4907***On Saliency Enhancement of Salient Pole Wound Field Synchronous Machines [#1378]*  
Wenbo Liu and Thomas.A Lipo   
, University of Wisconsin Madison, United States

Salient pole wound field synchronous machines (WFSMs) share similar torque characteristics as permanent magnet (PM) machines, but are free of permanent magnet material since a wound rotor winding instead generates the required field flux. In addition to cost advantages, the rotor field flux is readily varied making these machines attractive for traction and generator applications. This paper introduces flux barrier structure on rotor design to improve the saliency and thus the torque production of a conventional synchronous machine. Analysis are done using both dq- equivalent circuit model and finite element (FE) calculations. Flux barrier width is carefully tuned in FE analysis. Comparison is made to a conventional salient pole structure whereby a steady state torque improvement is achieved at rated to high stator current, and total loss is reduced in field weakening region.

**P4908***Fast and Accurate Analytical Calculation of the Unsaturated Phase Inductance Profile of 6/4 Switched Reluctance Machines [#847]*  
Sufei Li, Shen Zhang, Thomas Habetler and Ronald Harley   
, Georgia Institute of Technology, United States

Accurate calculation of the phase inductance profile of switched reluctance machines (SRMs) is of crucial importance in SRM design because it is a key parameter to predict the performance indices such as the torque and core loss. Instead of using the time-consuming finite element analysis (FEA) or the methods that require prior knowledge of magnetic fields from an FEA such as curve fitting and magnetic equivalent circuit (MEC), this paper proposes a fast and accurate analytical approach to determine the unsaturated phase inductance of an SRM at arbitrary rotor positions by solving the partial differential equations of magnetic scalar or vector potentials based on Maxwell equations. Conformal mapping is applied to deal with the non-radial or non-tangential geometric structures when calculating the inductance of the SRM. The agreement between the results of the proposed analytical method and FEA validates the analysis.

**P4909***An Analytical Approach for Determining Harmonic Cusps and Torque Dips in Line Start Synchronous Reluctance Motors [#1330]*  
Amir Negahdari, Vivek M. Sundaram and Hamid A. Toliyat   
, Texas AM University, United States

Excellence of line start synchronous reluctance motors (LS-SynRM) such as their high efficiency amongst other types of line start motors necessitates the existence of analytical methods in their design. The start-up period of these motors is of high importance and regarding this, the cage design needs to be discussed thoroughly since the squirrel cage is responsible for speeding up the motor to reach at synchronism. One of the issues in this sense is the rich harmonic content of the air-gap MMF arising from irregular bars configuration which afterwards could lead to creation of the torque dips in the torque-speed characteristic of the machine and making it incapable of synchronization under load. An analytical approach to calculate these harmonic effects while also considering the reluctance rotor contribution on them is proposed in this paper. This scheme starts from the stator winding configuration as a known parameter, obtaining the air gap MMF due to only the stator magnetic field, calculating the current and voltages induced through the rotor bars considering the effect of saliency using the model proposed in [1, 2]. Next, harmonic contribution of the rotor cage in the air gap MMF is derived. Finally, probable harmonic cusps and consequently torque dips is found in the torque-speed characteristic of the motor which is helpful in anticipating the synchronization capability under various loads. The results have been verified with a sample 4-pole, two flux barriers per pole LS-SynRM which suffers crawling due to the existence of the torque dips in its torque-speed characteristic. All simulations have been done by finite element analysis (FEA) software and a comprehensive program was written in Matlab to implement the proposed algorithm.

**P4910***Multi-Objective Design and Optimization of Generalized Switched Reluctance Machines with Particle Swarm Intelligence [#1421]*  
Shen Zhang, Sufei Li, Jie Dang, Ronald G. Harley and Thomas G. Habetler   
, Georgia Institute of Technology, United States; Faraday Future, Inc., United States

This paper proposes a fast and generalized multi-objective design and optimization method for the Switched Reluctance Machines (SRM). An analytical design model for SRMs with any feasible stator and rotor slot combinations is firstly developed, which can accurately evaluate a SRM design much faster than the prevalent finite element analysis (FEA) method. In addition, a novel method for multi-objective optimization of SRM is proposed based on this analytical model, and the number of prime variables to be optimized is reduced to only five. A canonical Particle Swarm Optimization (PSO) algorithm with penalty function is applied to find the optimal solution for a user defined objective function. After several rounds of searching process with the PSO, the optimal regions can be found for the design variables in terms of the performance indices (PIs). Finally, the optimized designs are validated by FEA. This method can generate the optimized SRM designs subject to different design requirements and accelerate the entire optimization process.

**P4911***Design and Comparison of Concentrated and Distributed Winding Synchronous Reluctance Machines [#1536]*  
Bastian Lehner and Dieter Gerling   
, Universitaet der der Bundeswehr Muenchen, Germany

This paper presents the design and comparison of two types of synchronous reluctance machines. The compared machines differ in their respective type of winding: One is equipped with a conventional full pitch distributed winding while the other one imparts an integer slot concentrated winding. Challenges for the application of concentrated windings to synchronous reluctance machines are examined. The tradeoff concerning a winding configuration with high winding factor and low space harmonic content is carved out. For the concentrated winding machine a winding configuration which is prioritizing a low space harmonic content over a high winding factor is chosen. Both machines were designed for equivalent performance requirements and design space. Finally, several calculations were done and the individual assets and drawbacks are opposed.

**P4912***Reduction in Torque and Suspension Force Ripples of an Axial-Gap Single-Drive Bearingless Motor [#131]*  
Junichi Asama, Kazumasa Takahashi, Takaaki Oiwa and Akira Chiba   
, Shizuoka University, Japan; Tokyo Institute of Technology, Japan

This paper investigates reduction in torque and suspension force ripples of an axial-gap type bearingless motor with one-degree-of-freedom (DOF) active positioning in the axial direction. This one-DOF controlled bearingless motor employs only one set of three-phase winding and one three-phase inverter, called a single-drive bearingless motor (SDBelM). The proposed axial-gap SDBelM combines a repulsive permanent magnetic coupling that stabilizes four- DOF radial and tilting motions. The suspension force and torque, which are regulated by the d- and q-axis currents, respectively, are theoretically derived considering the spatial harmonics of the flux density distribution induced from the permanent magnets. For reduction in torque and force ripples, we have proposed the improved magnet shape with the gap between the magnet pieces. The finite element method calculation shows that the proposed PM configuration is effective to reduce the torque and the suspension force ripples.

**P4913***Advancements in High Power High Frequency Transformer Design for Resonant Converter Circuits [#970]*  
Ashraf Said Atalla, Mohammed Agamy, Mark Dame, Liwei Hao, Gary Dwayne Mandrusiak, Konrad Weeber and Yan Pan   
, GE Global Research Center, United States

Medium and high frequency converters are gaining increasing interest for high power applications such as renewable energy and dc grids. Medium and high frequency transformers are an essential component in such converters. Advancing resonant converters to higher power levels challenges the transformer design in multiple aspects including power levels, switching frequency, ac and dc voltages insulation requirements and parasitic parameters. This paper presents design methods and recommendations for transformers that accomplish an industry- leading combination of power levels in the MW-class resonant frequencies up to 20kHz, operating AC voltages up to 5 kV, and dc offset voltages up to 300 kV. Design examples and test results of prototypes are presented along with results from applications where the transformers are integrated within high frequency converters.

**P4914***Active Damping of Ultra-fast Mechanical Switches for Hybrid AC and DC Circuit Breakers [#1026]*  
Chang Peng, Landon Mackey, Iqbal Husain, Alex Huang, Bruno Lequesne and Roger Briggs   
, North Carolina State University, United States; E-Motors Consulting, LLC, United States; Energy Efficiency Research, LLC, United States

An active damping method for Thomson coil actuated ultra-fast mechanical switches is proposed, including its control. Ultra fast mechanical switches are crucial for both DC and AC circuit breakers that require fast-acting, current-limiting capabilities. However, fast motion means high velocity at the end of travel, resulting in over-travel, bounce, fatigue, and other undesirable effects. The active damping proposed in this paper not only avoids such issues, but actually enables faster travel by removing limitations that would otherwise be necessary. This active damping mechanism is applicable in particular to medium and high voltage circuit breakers, but can be extended to actuators in general. A 15kV/630A/1ms mechanical switch, designed to enable the fast protection of medium voltage DC circuits, is used as a test-bed for the concept. It is based on the principle of repulsion forces (Thomson coil actuator). By energizing a second coil, higher opening speeds can be damped with limited over-travel range of the movable contact. The overall structure is simple, and the size of the overall switch is minimized. To validate the concept and to study the timing control for best active damping performance, both finite element modeling and experimental studies have been carried out.

**P4915***A Diagnosis Procedure in Standalone Mode for Inter Turn Short Circuit Fault of PMSMs through Modified Self-Commissioning [#846]*  
Yuan Qi, Mohsen Zafarani and Bilal Akin   
, Univeristy of Texas at Dallas, United States

In this paper, an comprehensive impedance analysis is proposed to detect inter turn short circuit fault in PMSMs at start-up. This method requires a very small computational load (less than 5% CPU bandwidth) and is easy to implement. The procedure is performed at start-up during standstill mode, and hence agnostic to well-known issues caused by transients, load/speed level or controller coefficient dependency. In order to distinguish the inter turn shorts from the eccentricity fault which exhibits similar behaviors, a classification algorithm is introduced based on stator resistor and inductances. Moreover, the effect of stator iron core saturation on the electric parameters analyzed in depth. Both 2-D FEA simulation and experimental test results are provided to show the efficacy of this method.

**P4916***Improved Condition Monitoring of the Faulty Blower Wheel Driven by Brushless DC Motor in Air Handler Unit (AHU) [#1185]*  
Chen Jiang, Thomas Habetler and Wen-Ping Cao   
, Georgia Institute of Technology, United States; Aston University, United Kingdom

The AHU (air handler unit) is one of the main research objects in HVAC (heating, ventilating and air conditioning) system containing coils, blower wheel, heater, etc. Most of the high efficiency blower wheels are driven by BLDC (brushless DC) motor. This paper mainly focuses on two severe problems in blower wheel, namely airflow blockage and unbalanced load of fan motor. Early diagnosis of these problems decreases energy consumption in HVAC system significantly. Condition monitoring method applied to both the stator current and stray flux is utilized in unbalanced load condition in a BLDC motor. The fundamental frequency and second harmonics of stray flux are analyzed as indicators under unbalance load condition. The discrimination between airflow blockage and unbalanced load based on stator spectrum analysis is also discussed in this paper. Some experiment results are given to prove that this method provides more efficacy and stability to diagnose the faults in blower wheel.

**P4917***Mitigation Method of the Shaft Voltage according to parasitic capacitances of the PMSM [#1219]*  
Jun-Kyu Park, Thusitha Wellawatta, Sung-Jin Choi and Jin Hur   
, University of Ulsan, Korea, Republic of; Incheon National University, Korea, Republic of

In this study, we propose the mitigation method of a shaft voltage according to change in parasitic capacitances of a permanent magnet synchronous motor (PMSM). First, we designed the equivalent circuit taking into account all parasitic capacitances. Then, we deducted that rotor-to-winding and stator-to- rotor capacitances mainly affect the shaft voltage. The stator-to-rotor capacitance depends on the air-gap length, which directly affects output torque characteristics of the motor. In case of the rotor-to-winding capacitance, it depends on the distance from the rotor to winding, which have effects on torque ripple, but it does not affect average torque of the motor. Thus, rotor-to- winding capacitance is determined as a variable for mitigation of the shaft voltage. According to change in the rotor-to-winding capacitance, we obtained and compared the results of the shaft voltage, average torque, and torque ripple.

**P4918***3-D Equivalent Magnetic Circuit Network for Precise and Fast Analysis of PM-assisted Claw-Pole Synchronous Motor [#288]*  
Jae-Han Sim, Dong-Gyun Ahn, Doo-Young Kim and Jung-Pyo Hong   
, Automotive Engineering, Hanyang University, Korea (South)

PM-assisted claw-pole synchronous motor (CPSM) has commonly been used in a variety of industrial applications, thanks to its robust structure and high energy density. However, such motor has an axially asymmetric rotor configuration, which induces the corresponding 3-D magnetic field distribution. Thus, this paper develops an infinitesimal hexahedron-element-based 3-D equivalent magnetic circuit network (EMCN) to estimate the performance of the PM-assisted CPSM. The hexahedron element can be considered as an optimum unit element in describing the configuration of the PM-assisted CPSM in detail. That eventually makes it possible to analyze the specific 3-D magnetic field distribution from which the flux-linkage, the back-electro motive force, the d- and q-axis inductances, and the electromagnetic torque are also being calculated. The results from the 3-D EMCN are compared with those from the 3-D FEA and/or the experiment so as to validate the accuracy. Finally, it is proved that the 3-D EMCN requires a shorter computing time than the 3-D FEA.

**P4919***Superconducting and Conventional Electromagnetic Launch System for Civil Aircraft Assisted Take-off [#471]*  
Luca Bertola   
, The University of Nottingham, United Kingdom

This paper compares three possible linear motor topologies for an electromagnetic launch system to assist civil aircraft take-off. Assisted launch of civil aircraft has the potential of reducing the required runway length, reducing noise and emissions near airports and improving overall aircraft efficiency through reducing engine thrust requirements. A comparison is made of practical designs of a linear induction motor, a linear permanent magnet synchronous motor and a superconducting linear synchronous motor to propel the A320-200 aircraft. The machine design requirements are established considering aerodynamic and engine performance and allow the aircraft to safely complete the take-off procedure. Analytical design of conventional synchronous and asynchronous linear motor will be compared with finite element analysis. A superconducting synchronous motor design is also considered, accounting for full system losses including the cryocooler power requirement and the mechanical and design constraints necessary for the cooler and the superconducting coils.

**P4920***Design of Integrated Radial and Dual Axial-Flux Ferrite Magnet Synchronous Machine [#537]*  
Shoji Shimomura and Takatoshi Sunaga   
, Shibaura Institute of Technology, Japan

Recently, significant attention has been paid to the use of ferrite magnets in the main traction machines of electric vehicles/hybrid electric vehicles (EVs/HEVs). However, while ferrite magnets are advantageous in terms of cost, they provide poor magnetic performance in comparison to the neodymium (NdFeB) magnets used in high-performance, high-efficiency machines with high torque densities. To overcome this issue, the application of axial-flux structures (AFSs) to ferrite magnets has been proposed, and it is anticipated that the extended air gap area created when an AFS is used could compensate for their poor magnetic properties. As an additional countermeasure, we propose an integrated radial and dual axial-flux (IRDAF) structure that has one radial-flux gap and two axial-flux gaps. Evaluations performed using finite element analysis show that a machine designed with our proposed IRDAF structure would provide good performance in terms of output torque, efficiency, and irreversible demagnetization.

Poster Session: Power Semiconductor Devices, Passive Components, Packaging, Integration, and Materials

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Giovanna Oriti, Enrico Santi

**P5101***Comprehensive Evaluation of a Silicon-WBG Hybrid Switch [#1423]*  
Amol Deshpande and Fang Luo   
, The Ohio State University, United States; the Ohio State University, United States

In this paper, a hybrid switch (HyS) consisting of a large silicon (Si) IGBT die in parallel with a small wide bandgap (WBG) die is proposed for generic power conversion drives. This HyS produces an inherent better conduction performance compared to the Si IGBT and WBG. A gate control option is recommended for minimum switching losses and switching frequency as high as 78 kHz can be achieved in HyS based converters. A parametric study was performed on the influence of the parasitic interconnect inductances within the switch. The recommended gate control option can be used for an inductance unbalance of less than 10 nH within the IGBT and WBG cell. For higher inductance an alternative gate control strategy is proposed for reduced switching losses. Experimental results show the benefits of the HyS. An algorithm is proposed for the optimum Si/WBG die current ratio. A case study involving transient thermal analysis is performed to show that a Si/WBG current ratio as high as 6:1 can be realized while ensuring the integrity of both dies.

**P5102***Characterization of Power Capacitors on Practical Current Condition Using Capacitor Loss Analyzer [#359]*  
Hironori Nagasaki, Pin-Yu Huang and Toshihisa Shimizu   
, Tokyo Metropolitan University, Japan; Tokyo Metropolitan University, Taiwan

In this study, the characteristics of capacitor are measured by using the function of B-H analyzer. In contrast to impedance analyzer measurement, the B-H analyzer can be used to measure capacitor characteristics under high current amplitude condition that approaches the practical current condition. In addition, the rectangular current waveform of a capacitor can also be measured under variable frequency and current conditions. Furthermore, loss evaluation of capacitor can be calculated through loss map method. The characteristics of three different dielectric capacitors-electrolytic, ceramic, and film-measured with sinusoidal and rectangular current waveforms, respectively, and discussed.

**P5103***A Practical Liquid-Cooling Design Method for Magnetic Components of EMI Filter in High Power Motor Drives [#176]*  
Jing Xue and Fred Wang   
, University of Tennessee, United States

This paper focuses on the liquid-cooling method of power inductors in electromagnetic interference (EMI) filters for high power motor drive application. A literature study on magnetic cooling methods with encapsulation, potting and liquid-cooled cold plate is carried out. An empirical evaluation method for potting effectiveness is proposed and validated with prototype encapsulation and example potting materials. One simplified experiment-based thermal modeling method for inductors is also developed with the purpose of avoiding time-consuming finite element simulation. Based on the potting evaluation method and simplified thermal modeling, one comprehensive design procedure is summarized.

**P5104***Efficiency Modeling of Wireless Power Transfer ASICs Accounting for Layout Parasitics [#387]*  
Rosario Pagano, Siamak Abedinpour, Angelo Raciti and Salvatore Musumeci   
, Analog and Power Division, Integrated Device Tec, United States; DIEEI, University of Catania, Italy

This paper presents a power-loss model for Lateral-Diffused MOSFETs (LDMOSs) in application-specific integrated circuits (ASICs) in the field of wireless power-transfer system applications. Both the transmitter and receiver power-stages integrated in their respective ASIC units were considered, and the total system efficiency was subsequently estimated. Layout parasitics pertaining to the primary and secondary integrated circuits (ICs) have been considered due to their impact on the total system efficiency, and a charge-sheet control model for the LDMOSs of the three power stages has been developed. Thermal effects induced by heating within the two ASICs were also included, as they exert a significant influence on the amount of both conduction and switching losses. Model results and experimental data are compared and show a satisfactory agreement.

**P5105***Direct Voltage Balancing for Series Connected IGBTs [#829]*  
Xueqiang Zhang, Jin Zhang and Patrick Palmer   
, University of Cambridge, United Kingdom

Operating Insulated Gate Bipolar Transistors (IGBTs) in series is of interest due to its ability to extend the overall blocking voltages of existing DC circuits. Regulating the voltage sharing for series connected IGBTs has been attempted in various ways. This paper presents an approach using the idea of Active Voltage Control (AVC) to improve upon the series voltage sharing performance previously achieved using AVC. The design considerations are discussed and experimentally attempted. The internal IGBT physics regarding this active voltage regulation is also discussed and the future work is suggested.

Poster Session: Energy Efficiency Systems and Applications

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Pericle Zanchetta, Mohammad Anwar

**P5301***Mitigation of Harmonics in Drilling Rigs using Shunt Active Power Filters [#981]*  
Muhammed Fasil Tp, Abdul R Beig, Rajasekharareddy Chilipi, Saikrishna Kanukollu, Naji Al Sayari and Khalifa Al Hosani   
, The Petroleum Institute, United Arab Emirates

Harmonics and low power factor are major concerns in modern industry. Even though several solutions are available, mitigating these problems in already established heavy industries is still a challenge. On-shore oil rigs are one such case where the problem becomes unique because of the extreme operating conditions and limited space. This paper presents a case study of mitigating the harmonic problem in on-shore oil rigs operating in deserts. It is proposed to use multiple shunt active power filters. One or more shunt active filters may go out of operation but the drives continue to run without filters resulting in distortion of voltage. The active filters which are in operations should work under distorted voltage conditions. Operation of shunt active power filter under distorted voltages is demonstrated both through simulation and experiments.

**P5302***Variable Switching Frequency Algorithm for Optimal Tradeoff between Switching Losses and Total Demand Distortion in Grid-Tied Three-Phase Voltage-Source Inverters [#879]*  
Hamzeh Jamal, Saher Albatran and Issam Smadi   
, Jordan University of Science and Technology, Jordan

The switching frequency at which the inverter operates is an important parameter that significantly affects the operation of the inverter. In this paper, a new variable switching frequency algorithm is proposed in which the switching frequency is varied in response to the variation in the operating conditions. The proposed algorithm is based on multi-objective optimization problem formulation such that a weighted sum of the switching losses in the inverter and the Total Demand Distortion (TDD) in the inverter's output current is to be minimized. A behavioral model for the switching devices and a TDD model based on the time-domain ripple analysis are adopted. This made the formulation of the problem to be very clear and easy to be implemented in the digital controller. Therefore, the optimal switching frequency can be determined online. The proposed algorithm can increase the efficiency of the inverter without deteriorating the harmonic performance. Moreover, the lifetime of the inverter can be increased due to the narrower junction temperature profile that can be achieved by this algorithm when compared to the fixed switching frequency counterpart. The effect of the ambient temperature is taken into account and the switching frequency is varied accordingly. The algorithm is implemented on the Field-Programmable Gate Array (FPGA) platform. The effectiveness of the proposed algorithm has been verified experimentally

**P5303***A Hybrid Model Predictive Charging Control Strategy for Ultracapacitors of Urban Rail Vehicles [#524]*  
Yuanjun Chen, Xiaoyong Zhang, Zhiwu Huang, Jun Peng, Zheng Xu and Yanhui Zhou   
, Central South University, China

Ultracapacitors have been widely used in urban rail vehicles as the power source because of its high power density. However, it is still a challenge to design a rapid and reliable charging control system for ultracapacitors since the DC-DC converters are highly nonlinear along with hard constraints. In this paper, the piecewise-affine (PWA) model of the ultra-capacitor charging system and a hybrid model predictive control strategy are proposed to address this challenge. The hybrid nature of the converter is taken into account in v- resolution model which can reflect the dynamics of the charging system precisely. Based on the discrete-time model, we formulate and solve a constrained optimal control problem, and the control law is calculated offline using multi-parameter programming method. Simulation and experiment results validate the potential advantages of the proposed scheme.

**P5304***A Universal-Input Single-stage AC-DC Converter for Twin-Bus Type High-Power LED applications [#1251]*  
Hongbo Ma, Gang Chen, Yi Junhong, Meng Qingwei and Sha Deshang   
, Southwest Jiaotong University, China; Beijing Institute of Technology, China

In the high-power LED driver system, a singlestage boost-LLC type soft-switched AC-DC converter is usually employed for obtaining the high efficiency and low cost. However, the high bus voltage is its fatal disadvantage due to the PFM control strategy. Thus, this LED driver is only applied in the low ac input voltage case. In order to overcome this problem, an asymmetric PWM (APWM) feed-forward strategy is proposed in this paper. The proposed control method can reduce significantly the bus voltage. The detailed operation principle and design consideration for the proposed control strategy are analyzed and discussed. The feature of the proposed solution was demonstrated using a universal-input 100-W hardware prototype. The experimental results showed the converter achieves full-range ZVS for primary switches and the efficiency of 92% under the 120V input voltage.

**P5305***Control IC for TRIAC Dimming LED Driver with Quasi-Resonant Flyback Converter [#156]*  
Tsorng-Juu Liang, Shih-Wen Tsai, Kai-Hui Chen and Ta-Wei Huang   
, National Cheng Kung University, Taiwan

In this paper, a TRIAC dimmable controller for quasi-resonant flyback LED driver is realized. This controller is fabricated with TSMC 0.25 micri meter 60 V CMOS high voltage mixed signal general purpose process and applied to an input voltage of 90 to 264 Vrms, output voltage of nominal 40 V, and constant output current of 600 mA/24W hardware prototype to verified the feasibility of the proposed control.

Poster Session: Emerging Technologies and Applications

Tuesday, September 20, 3:00PM-4:30PM, Room: Exhibit Hall, Chair: Jin Wang, Yaosuo "Sonny" Xue

**P5501***Mutual Inductance Measurement for Power Device Package Using Time Domain Reflectometry [#1391]*  
Kazunori Hasegawa, Keiji Wada and Ichiro Omura   
, Kyushu Institute of Technology, Japan; Tokyo Metropolitan University, Japan

Stray inductance inside power device package will be a constraint on improvement of power density as well as switching frequency in power converters because the converters will suffer from electromagnetic interference (EMI)-related problems. This paper proposes a measurement method of mutual inductance for power device packages using time domain reflectometry. The method is characterized by introducing four-terminal measurement that distinguishes self and mutual inductances among collector, emitter, and gate terminals. A measurement fixture for a discrete IGBT is designed, constructed, and tested to ensure repeatability of the proposed method. Experimental results verifies the viability of the proposed method.

**P5502***Synchronized triple bias-flip circuit for piezoelectric energy harvesting enhancement: operation principle and experimental validation [#1414]*  
Yuheng Zhao and Junrui Liang   
, ShanghaiTech University, China

The power conditioning circuit plays an important role in a piezoelectric energy harvesting (PEH) system. Sophisticatedly designed circuit can increase the harvesting capability by several times. The synchronized multiple bias-flip (SMBF) model generalizes the performance of existing interface circuits and offers prospect for future circuit evolution. Among all ideal SMBF derivatives, the parallel synchronized triple bias-flip (P-S3BF) circuit makes the best compromise between cost and effectiveness. This paper introduces a practical implementation of P-S3BF. It is realized by an inductive current-routing network, which is controlled by six MOSFET switches. The steady-state operation principle towards PEH enhancement is analyzed in detail. The transient behavior is also illustrated for highlighting the adaptive feature of the new circuit. Both theoretical and experimental results show that, under the same harmonic displacement excitation, the prototyped P-S3BF circuit can increase the maximum harvested power by 24.5% compared to the cutting-edge parallel synchronized switch harvesting on inductor (P-SSHI) circuit, and 287.6% compared to the standard bridge rectifier circuit.

**P5503***Approaching Repetitive Short Circuit Tests on MW-Scale Power Modules by means of an Automatic Testing Setup [#1558]*  
Paula Diaz Reigosa, Huai Wang, Francesco Iannuzzo and Frede Blaabjerg   
, Aalborg university, Denmark; Aalborg University, Denmark

An automatic testing system to perform repetitive short-circuit tests on megawatt-scale IGBT power modules is presented and described in this paper, pointing out the advantages and features of such testing approach. The developed system is based on a non-destructive short-circuit tester, which has been integrated with an advanced software tool and a semiconductor device analyzer to perform stress monitoring on the considered device under test (DUT). A case-study is included in the paper concerning a 1.7 kV/ 1 kA IGBT module, which has been tested safely up to 30,000 repetitions with no significant damage. The developed system has been demonstrated to be very helpful in performing a large number of repetition tests as required by modern testing protocols for robustness and reliability assessment. The software algorithm and a demonstration video are available for download.

**P5504***Cascaded Operation of SiC JFETs in Medium Voltage Solid State Circuit Breakers [#1584]*  
Aref Moradkhani Roshandeh, Zhenyu Miao, Zaki Ahmad Daniyal, Yanjun Feng and Zheng John Shen   
, Illinois Institute of Technology, United States

This paper reports cascaded operation of 1200V normally-on SiC JFETs in a solid state circuit breaker (SSCB) designed for medium voltage DC systems. The SSCB detects the short circuit fault by sensing the voltage rise between its two terminals and consequently uses this fault condition to power up the control circuit to turn and hold off the SiC JFETs to interrupt the fault current. Voltage sharing and balancing among the cascaded SiC JFETs during the fault current interruption process are important design considerations. Both simulation and experimental work are performed to identify an optimal circuit solution. The final SSCB prototype experimentally demonstrated a fault current interruption capability up to 125 amperes at a DC bus voltage of 1000 volts within 2.5 micro seconds.

**P5505***Hybrid Algorithm for Fault Locating in Looped Microgrids [#1716]*  
Siavash Beheshtaein, Mehdi Savaghebi, Juan Carlos Vasquez and Josep Guerrero   
, Aalborg University, Denmark

Protection is the last obstacle to realizing the idea of microgrid. Some of the main challenges in microgrid protection include topology changes of microgrid, week-infeed fault, bidirectional power flow effects, blinding of the protection, sympathetic tripping, high impedance fault, and low voltage ride through. Besides, these challenges it is desired to eliminate the relays for distribution lines and locate faults based on distributed generations (DGs) voltage or current. On the other hands,, increasing in the number of DGs and lines would result in high computation burden and degradation the efficiency and accuracy of the methods that utilize all these information. This paper deals with this issue by analyzing only DG's voltage. In the first step, a fault is detected by the voltage of each DG, then the DG with the highest voltage collapse injects voltage harmonic with 333 Hz to find another DG that fault occurs within them. Two criteria are also defined in such a way to prevent injection of voltage harmonic by the other DGs. Finally, the fault is located in the reduced space of search by wavelet transform and optimized multiclass support vector machine. In the simulation results the contribution of this method is shown and results also validate the efficiency of the proposed method.

Wednesday, September 21, 8:30AM-10:10AM

Photovoltaic Converters II

Wednesday, September 21, 8:30AM-10:10AM, Room: 203AB, Chair: Nathan Weise, Jaeho Choi

**8:30AM***A 50kW High Power Density Paralleled-five-level PV Converter based on SiC T-type MOSFET Modules [#502]*  
Yanjun Shi, Yuxiang Shi, Lu Wang, Ren Xie and Hui Li   
, FSU, United States

SiC T-type LCL inverter can achieve smaller device loss than two-level topology, however its improvement on power density is limited by current ripple loss on magnetic components as switching frequency increases. This paper presents a paralleled-five-level (P5L) PV inverter which achieves better utilization of SiC devices than traditional T-type three-level (3L) LCL topology at higher switching frequency. Comparison of the SiC P5L PV inverter with SiC T-type 3L LCL PV inverter has been presented. The design challenges and methods to solve magnetic balancing, short circuit protection, and digital controller computation time issues are analyzed. A 50kW PV converter including boost stage and inverter stage has been built in the laboratory, which achieves a power density of 22.7 W/in3 and 2.5 kW/kg, and measured peak efficiency of 99.2%.

**8:55AM***PV Array Voltage Range Extension for Photovoltaic Inverters Using a Mini-Boost [#1221]*  
Emanuel Serban, Francisco Paz and Ordonez Martin   
, ECE Department, Univ. of British Columbia, Canada

Photovoltaic (PV) plants are designed at higher voltage and lower current operation in order to reduce the overall system installation cost. Multiple PV modules connected in series are prone to shading problems which leads to loss of energy harvested. PV inverters without a boost stage are more efficient, by removing the additional power stage, but are prone to energy harvesting loss when the array is partially shaded and the voltage drops below the minimum operating voltage. Instead, PV inverters equipped with a boost stage improve the range of conditions where energy can be harvested but add additional losses to the system reducing the efficiency. In this paper, a new converter power stage topology design and methodology optimization is proposed in the form of a mini-boost, a cost-effective and attractive solution to the traditional approach. The mini-boost extends the DC voltage range for energy harvesting under shading conditions and low irradiance conditions and only needs to process a fraction of the power leading to a cost effective and attractive solution. A comparative analysis under different irradiance levels is presented to illustrate the advantages in energy harvesting obtained with the mini-boost solution. Simulations and experimental results using a dual mini-boost dc-dc stage and 3 phase 3-level neutral point clamped inverter level are presented to validate the proposed dc-bus extension range for energy harvesting.

**9:20AM***Submodule Integrated Boost DC-DC Converters with No External Input Capacitor or Input Inductor for Low Power Photovoltaic Applications [#1462]*  
Jen-Hung Huang, Brad Lehman and Ting Qian   
, Northeastern University, United States; Tongji University, China

This paper proposes to utilize the internal solar cell diffusion capacitance and internal solar module wire parasitic inductances to replace the input capacitor and filter inductor in boost derived DC-DC converters for energy harvesting applications. High switching frequency (MHz) hard switched and resonant boost converters are proposed. Analysis, simulation and experimental prototypes are presented. A specific proof-of-concept application is especially tested for foldable photovoltaic (PV) panels, which are known for their high internal wire inductance. The experimental converters successfully boost solar module voltage without adding any external input capacitance or filter inductor.

**9:45AM***Effective Control Approach for Multi-PVs Based Resonant Converter through Cross-switched Structure [#1467]*  
Ali Elrayyah, Amr Ibrahem and Yilmaz Sozer   
, Qatar Environmental and Energy Research Inst, Qatar; University of Akron, United States

To support the integration of more PV sources with utility grids, there is a need for low cost and efficient power electronics converters. In this paper, the structure of cross-switch multilevel inverter (CRM) is proposed to interface more than one PV modules with a resonant converter. CRMs treat each pair of PV modules as one unit during the positive and negative half cycles and this could go against the need to track the maximum power point of each PV module individually. In this paper, a control method is proposed to achieve MPPT of individual modules. Basically, the paring of PV modules in the positive half cycle is made different from that in the negative half cycle which allows the MPPT of each module to be achieved effectively. Moreover, the MPPT of the modules is achieved through distributed controller to enhance the system scalability. Through simulation studies, the effectiveness of the proposed system is verified and its advantages are clearly demonstrated.

Converter Applications for Alternative Energy Systems

Wednesday, September 21, 8:30AM-10:10AM, Room: 203C, Chair: Andrew Hintz, Shaojun Xie

**8:30AM***Control Scheme for the Wide Operation Range of Induction Generator with a Vienna Rectifier in Wind Turbine Systems [#338]*  
Jin-Hyuk Park, June-Seok Lee and Kyo-Beum Lee   
, Ajou University, Korea (South); KRRI, Korea (South)

This paper proposes a control scheme for the wide operation range of an induction generator (IG) with a Vienna rectifier. A Vienna rectifier has the limited operation range because the sign of the current should be the same as that of the voltage in the normal operation. For this reason, the power factor of a Vienna rectifier is also limited. In the IG, the d-axis stator current is necessary for the self-excitation of the IG. Usually, the d-axis stator current is controlled to the rated d-axis current, which means that IG can operate in the low power factor. Therefore, the operation range of the IG with a Vienna rectifier is narrow. The proposed control method adjusts the d-axis current appropriately to extend the operation range and to include the operating power factor in the feasible operation range of a Vienna rectifier. The analysis results of the proposed method are verified from PSIM simulations with a 150-kW IG system using a Vienna rectifier.

**8:55AM***GaN Based High Gain Non-Isolated DC-DC Stage of Microinverter with Extended-Duty-Ratio Boost [#1490]*  
Jinia Roy and Raja Ayyanar   
, Arizona State University, United States

Microinverter is attracting more attention due to its compact size, plug and play concept, easy installation, and higher power yield under partial shading condition. This paper explores a converter for the DC-DC stage of a non-isolated microinverter. The topology termed as extended-duty-ratio (EDR) boost, is a hybrid of the interleaved boost and switched capacitor concept which has the advantage of providing high gain but simultaneously maintaining reduced voltage and current stress on most of the switches. The inductor current is interleaved, reducing the equivalent ripple on the converter input current and the inductor power loss. The converter operation is identified to be divided into different zones depending on the duty ratio of the phases. The operating principles along with the details of the component design and loss analysis as a function of converter phases has been studied. A 250 W GaN based 3-level EDR prototype with input from 20-40 V and 225 V output and operating at switching frequency of 200 kHz has been developed to validate operation of the converter in hardware.

**9:20AM***High-Efficiency Three-Level SEPIC for Grid-Tied PV Systems [#1491]*  
Min-Kwon Yang, Seung-Jae Lee, Jun Heo and Woo-Young Choi   
, Chonbuk National University, Korea (South)

The two-level single-ended primary-inductor converter (SEPIC) has been used for grid-tied photovoltaic (PV) systems. However, it has high switching losses because of high voltage stresses. To reduce the switching losses, a three-level SEPIC is suggested in this paper. The three-level SEPIC has low switching losses by reducing the switch voltage stress. It improves power efficiency by using a lower-voltage-rated switch compared to the switch in the two-level SEPIC. The capacitor voltage balance control is presented with a maximum power point tracking (MPPT). Experimental results for a 1.0 kW prototype system are discussed with a grid-tied transformerless H6 inverter.

**9:45AM***A Novel Zero-voltage-switched Multi-resonant DC-DC Converter [#1570]*  
Ling Gu and Ke Jin   
, Nanjing University of Aero. and Astro., China

This paper proposes a novel zero-voltage-switched multi-resonant DC-DC converter. With the resonance between the resonant inductor and the resonant capacitors paralleled with the main switch and rectifier diode, the proposed converter achieves zero- voltage-switching (ZVS) operation of the semiconductors. The resonance components absorb all parasitic components, including the transformer leakage inductance, switch output capacitance and diode junction capacitance. The topological modes, operation principles and dc characteristics are presented in detail. A prototype based on the proposed topology was built in the lab to verify the theoretical analysis.

Modeling, Analysis, and Control of Grid-Connected Converters I

Wednesday, September 21, 8:30AM-10:10AM, Room: 202D, Chair: fred wang, Paolo Mattavelli

**8:30AM***Seamless Transfer Strategy Considering Power Balance in Parallel Operation [#121]*  
Chee Seung-Jun, Lee Younggi, Son Young-Kwang, Sul Seung-Ki, Lim Changjin and Huh Sungjae   
, Seoul National University, Korea (South); LG Electronics, Korea (South)

This paper presents a power reference modifier for seamless transfer considering the power balance in the parallel operation. When the PCS (Power Conditioning System) is disconnected from the grid, the PCS should operate in the stand-alone mode to supply energy to the critical loads. If multiple PCSs work as one PCS, slave PCSs maintain the current control mode even if master PCS change its control mode from the current control to the voltage control. If the power references of slave PCSs are not changed properly based on the load condition, the power balance condition may not be met. In that case, the voltage applied to the critical loads might be beyond or below the rated voltage. To avoid this phenomenon, the power values absorbed into the loads should be monitored consistently and the power references of the slave PCSs should be modified properly based on them. But the master PCS which transfers the power references to the slave PCSs and works as voltage source in stand- alone mode can obtain it indirectly by calculating its own power values without monitoring the power consumed by critical loads. Using those, simple controller for modifying the power references of the slave PCSs can be configured. The effectiveness of the proposed power reference modifier has been verified through the experimental results. By applying the proposed method, the transition from the grid-connected mode to the stand-alone mode works satisfying Computer Business Equipment Manufacturers Association (CBEMA) curve.

**8:55AM***Robust Control for Parallel Operated L-Inverters with Uncertainty and Disturbance Estimator [#229]*  
Yeqin Wang, Qing-Chang Zhong and Beibei Ren   
, Texas Tech University, United States; Illinois Institute of Technology, United States

In conventional droop control, accurate proportional load sharing could not be achieved among parallel operated inverters due to the mismatch of output impedance and system disturbances. In this paper, an uncertainty and disturbance estimator (UDE)-based robust droop control strategy is proposed for accurate proportional load sharing, particularly reactive power sharing, among parallel operated L- inverters. The reactive power dynamics is derived from power delivery equation passed by a low-pass filter, while the reactive power reference is designed with the feedback of load voltage. , and tThe reactive power control is developed based on UDE-based method. The model nonlinearity and uncertainty (e.g., power angle), and system operation disturbances (e.g., change of output impedance, and load change), can be estimated and compensated by this UDE-based robust droop control. Experimental validation is provided to show the effectiveness of the proposed method.

**9:20AM***Active and Reactive Power Operational Region for Grid-Interactive Cascaded H-Bridge Multilevel Converters [#1062]*  
Jacob Lamb and Mirafzal Behrooz   
, Kansas State University, United States

Cascaded h-bridge (CHB) multilevel converters are being considered as a promising option for interfacing renewable energy resources with the grid, due to their modularity, scalability, and increased efficiency when compared to traditionally used two-level inverters. When used as grid interfaces, CHB converters should be capable of controlling the injected active and reactive power while also satisfying operating criteria such as grid standards, e.g. IEEE 519. This paper aims to identify practically available operating points in the PQ plane when using a grid-interactive CHB converter, and to determine the factors which prevent utilization of other operating points. This work (i) provides distribution engineers with information regarding the active and reactive power which can feasibly be generated by a grid-interactive CHB converter, (ii) creates a framework for assessing operating point trajectories when altering the steady-state operation of grid-tied CHB converters, and (iii) provides a basis for selecting and modifying steady-state PWM generation techniques in order to meet desired performance criteria. Simulation data are presented to verify the findings of this work.

**9:45AM***Harmonic Stability Analysis and Controller Parameter Design of Three-Phase Inverter-Based Multi-Bus Ac Systems Based on Sequence Impedances [#1331]*  
Wenchao Cao, Yiwei Ma and Fred Wang   
, The University of Tennessee, Knoxville, United States

Three-phase inverter-based multi-bus ac systems could suffer from the small- signal instability issue due to the dynamic interaction among inverters and passive components in the systems. To address this issue, this paper proposes two harmonic stability analysis methods and an inverter controller parameter design approach for stable system operation. The proposed sequence-impedance-based harmonic stability analysis methods can reduce the computation effort by avoiding the calculation of right-half-plane poles of impedance ratios, as compared with the impedance-based analysis method using Nyquist stability criterion. Therefore, the controller parameters can be designed in the forms of stability regions in the parameter space, by repetitively applying the proposed stability analysis methods. In addition, the proposed stability analysis methods enable the system stability by using only measured component impedances. Experimental results of an inverter- based two-area system validate the effectiveness of the proposed stability analysis methods and parameter design approach.

Utility Applications II

Wednesday, September 21, 8:30AM-10:10AM, Room: 202A, Chair: Deepak Divan, Alireza Nami

**8:30AM***Full-ZVS Modulation for All-SiC ISOP-Type Isolated Front End (IFE) Solid-State Transformer [#583]*  
Jonas E. Huber, Daniel Rothmund, Li Wang and Johann W. Kolar   
, Power Electronic Systems Lab, ETH Zurich, Switzerland; FREEDM Systems Center, NC State University, United States

Thanks to their comparatively low system complexity, SSTs based on an isolated front end (IFE) approach are suitable for space and weight-constrained medium voltage (MV) AC to low voltage (LV) DC power supply applications, e. g., in future traction, naval, subsea or aerospace systems. The IFE approach connects series resonant isolation stages operating in the half-cycle discontinuous- conduction-mode (HC-DCM) directly to the MV AC grid in an input-series, output- parallel (ISOP) configuration, but the entire control, i.e., the shaping of the grid current for unity power factor and output voltage regulation, is carried out by a second, non-isolated conversion stage on the LV side. However, since the isolation stages do not operate with a DC but with an AC or rectified AC input voltage, the transformer magnetizing current available for ZVS as well as the voltage to be switched vary over the grid period. Taking into account also component tolerances among the cascaded converter cells, this paper provides an in-depth analysis of the ZVS behavior under these conditions, and of the associated losses and EMI considerations, presenting a loss-optimal choice of the magnetizing inductance value and of the dead time (interlock time) of the isolation stages' bridge legs. A time-dependent variation of the latter to achieve ZVS over the entire grid period without an increase of the isolation stage losses is proposed. The considerations are verified at the example of the Swiss SST (S3T), an all-SiC 25 kW, 6.6 kV MVAC to 400 V LVDC converter system, using a detailed simulation model, including non-linear MOSFET capacitances.

**8:55AM***Stability issues in reverse power flow limitation in a Smart Transformer-fed distribution grid [#666]*  
Giovanni De Carne, Giampaolo Buticchi and Marco Liserre   
, Christian-Albrechts University of Kiel, Germany

The increasing implementation of Distributed Generation (DG) in the distribution grids creates new challenges in controlling the voltage profile. If the DG production exceeds the load consumption, the power flow reverses through the MV/LV substations. The reverse power flow impacts mainly on the voltage profile, increasing further the voltage in LV and MV grids. At this regard the Smart Transformer offers a new possibility to avoid the reverse power flow in the MV grids. The ST can adapt the voltage waveform modifying the frequency in order to interact with the local DG: the DG PLL notices the frequency change and the generators, equipped with droop controllers, decrease their power output. This paper deals specifically with the stability issues of the DG PLL when a fast change in the frequency is applied for avoiding the reverse power flow in MV grid. If the PLL in the DG is tuned with a low bandwidth, it could result in oscillatory phenomena in the current controller of the DG. The evaluation of the stability analysis has been performed analytically and validated by means of Control-Hardware-In- Loop (CHIL).

**9:20AM***Smart Transformer-Based Hybrid Grid Loads Support in Partial Disconnection of MV/HV Power System [#774]*  
Chandan Kumar, Zhixiang Zou and Liserre Marco   
, Indian Institute of Technology Guwahati, India; Christian-Albrechts-University of Kiel, Germany

Double circuit lines are common for transmitting the electrical power in high voltage (HV) and/or medium voltage (MV) power system. During the faults in one of the lines or transformers of the double circuit lines, one line is disconnected from the system and the healthy line is utilized for supplying the entire load. In that case, the transformer supplying the entire load could be overloaded. For the safe operation of the transformer, it is needed to disconnect some of the loads. This partial disconnection of MV/HV power system can severally effect the performance of critical loads. Recently, power electronic based transformer equipped with effective control and communication called smart transformer (ST) has been proposed for installation in the distribution system in place of conventional transformer. One of the most important feature of ST is to allow for connection of ac and dc grid forming hybrid grid which allow easy integration of renewable energy sources and storage. Considering these feature of ST, this paper proposes a new functionality of the ST where it provides continuous power to a section of the loads during the partial disconnection of MV/HV power system and improves the performance of power system. This new feature of ST has been proved through power system computer aided design (PSCAD) software based simulation results. Power hardware in loop (PHIL) and control hardware in loop (CHIL) is under development to test the idea.

**9:45AM***Soft-Switching Solid State Transformer (S4T) [#1354]*  
Hao Chen and Deepak Divan   
, Georgia institute of technology, United States

This paper presents a new topology for a fully bidirectional soft-switching solid state transformer (S4T). The minimal topology, featuring 12 main devices and a high-frequency transformer, does not use an intermediate DC voltage link, and provides sinusoidal input and output voltages. The S4T can be configured to interface with two- or multi-terminal DC, single- or multi-phase AC systems. An auxiliary resonant circuit creates zero-voltage-switching (ZVS) conditions for main devices from no-load to full-load, and helps manage interactions with circuit parasitic elements. The modularized structure allows series and/or parallel stacking of converter cells for high-voltage and high- power applications.

DC Microgrids I

Wednesday, September 21, 8:30AM-10:10AM, Room: 203DE, Chair: Giovanna Oriti, Babak Parkhideh

**8:30AM***Hierarchical Coordination of a Hybrid AC/DC SmartGrid with Central/Distributed Energy Storage [#1518]*  
Pablo Arboleya, Cristina Gonzalez-Moran, Pablo Garcia, Jorge Garcia and Bassam Mohamed   
, University of Oviedo, Spain

This work describes a hybrid AC/DC Smart Grid distribution scheme installed at LEMUR microgrid laboratory. The control of the microgrid is carried out according to a hierarchical coordination considering the high level control. The configuration includes a microgrid (uG) connected to the main utility grid (MUG) by means of a solid state transformer (STT). The uG is formed by several nanogrids (nGs). All (nGs) are based on four wire configurations, as they are usually employed in AC distribution systems. However, the scheme is considered as a hybrid Smart Grid because the connection among different nanogrids and with the SST are DC connections. The SST is also equipped with a third port connected to a central energy storage system (CESS). The coordination between the different involved in the systems: the installed dispersed generators at nanogrid level, the nanogrids, the SST and the CESS has been implemented using a bottom-up hierarchical approach. Several configurations at nanogrid and microgrid levels are shown and analyzed. For making the coordination of the different elements of the microgrid, a fast power flow algorithm for estimating the state of the microgrid in real time was developed. In this paper the proposed structure is described paying special attention to the power flow algorithm. The results obtained with the power flow algorithm in simulations were validated at laboratory level.

**8:55AM***Dynamic Optimal Power Flow for DC Microgrids with Distributed Battery Energy Storage Systems [#23]*  
Thomas Morstyn, Branislav Hredzak and Vassilios Agelidis   
, University of New South Wales, Australia

This paper proposes a model predictive control strategy for power flow optimisation between battery energy storage systems distributed in a DC Microgrid. The proposed control strategy uses a new convex formulation of the DC microgrid dynamic optimal power flow problem, based on a static voltage-current model and linear power flow approximations. Unlike optimisation strategies based on a single bus model, line losses and line voltage drops are included in the optimisation. The availability of fast and robust solvers for convex optimisation problems makes this a scalable solution for a real-time model predictive control implementation. To verify the performance of the proposed control strategy, real-time simulations were carried out for a DC microgrid with distributed lead-acid batteries and intermittent photovoltaic generation. The simulations were completed on an RTDS Technologies real-time digital simulator, using switching converter models and non-linear battery models.

**9:20AM***DC Electric Springs with Modified Droop Control for Storage Reduction in DC Microgrids [#282]*  
Ming Hao Wang, Shuo Yan, Siew Chong Tan and Shu Yuen Ron Hui   
, The University of Hong Kong, Hong Kong

Series DC electric springs (series ESs) can be a cost-effective technology to tackle the intermittency of the renewable generations in DC distribution grids. When multiple series ESs are connected to differently rated non-critical loads (NCLs) and are operated to regulate the voltages at their respective points of common coupling, the charging and discharging characteristics among the ESs are different. In this paper, a modified droop controller, which is designed to reduce the total storage capacity of the series ES, is proposed to coordinate the operation of multiple series ESs. The power curves of series ESs with light, medium, and heavy NCLs are compared and analyzed. Experimental results on a 60 V DC grid have confirmed that the proposed controller can effectively reduce the total storage capacity with good coordination among multiple series ESs.

**9:45AM***Optimal Droop Surface Control of Dc Microgrids Based on Battery State of Charge [#53]*  
Arthur Jones and Wayne Weaver   
, Michigan Technological University, United States

For a microgrid with a high penetration level of renewable energy, energy storage use becomes more integral to the system performance due to the stochastic nature of most renewable energy sources. This paper examines the use of droop control of an energy storage source in dc microgrids in order to optimize a global cost function. The approach involves using a multidimensional surface to determine the optimal droop parameters based on load and state of charge. The optimal surface is determined using knowledge of the system architecture and can be implemented with fully decentralized source controllers. The optimal surface control of the system is presented. Derivation of a cost function along with the implementation of the optimal control are included. Results were verified using a hardware-in-the-loop system.

Transportation Electrification I

Wednesday, September 21, 8:30AM-10:10AM, Room: 102D, Chair: Bulent Sarlioglu, Tim Burress

**8:30AM***A Modified Z-source Converter based Single Phase PV/Grid Inter-connected DC Charging Converter for Future Transportation Electrification [#1015]*  
Siddhartha A. Singh, Giampaolo Carli, Najath A. Azeez and Sheldon S. Williamson   
, University of Ontario Institute of Technology, Canada; EMD Technologies - Heico Corporation., Canada

Use of renewable sources of energy for charging of electric vehicle(EV) batteries have generated tremendous interest. The use of off-board DC chargers to reduce the weight and increase space inside an electric vehicles has been an important area of interest. Harvesting solar energy to charge electric vehicle batteries can result in large inefficient systems when multiple power conversion stages are present. On the other hand,integration of renewable sources of energy with the grid can reduce the dependency on the AC grid while charging an Electric Vehicle(EV) and also the use of fossil fuels to generate more energy. In this paper, a single stage PV grid integrated modified z source inverter is presented. The component sizing, modeling and different modes of operation have been presented.

**8:55AM***Comprehensive design comparison of using different order harmonics as the power carrier in wireless power transfer for PHEV and EV Wireless Charging [#561]*  
Hulong Zeng and Fang Z. Peng   
, Michigan State University, United States

A series resonant converter (SRC) with third harmonic as the power carrier has been verified with the benefit of reducing the resonant components to one third. With proper design, it can have competitive efficiency with that using fundamental power, while the siaze and weight are much smaller. However, there is a trade-off between using a highter order harmonic and the larger current stress on the primary side. In this paper, a comprehensive design comparison of using different order harmonics as the power carrier in wireless power transfer for plug-in hybrid electric vehicle (PHEV) and electric vehicle (EV) wireless charging is presented. The comparison mainly focuses on overall efficiency and each component's stress. A guideline for choosing the optimal order or harmonic as power carrier is discussed after the comparison. A 1-kW prototype with 20-cm air gap using harmonic power is built to verify the proposed method.

**9:20AM***A New Inductive Wireless Power Transfer Topology Using Current-Fed Half-Bridge CLC Transmitter LC Receiver Configuration [#608]*  
Akshay Rathore and Suvendu Samanta   
, Concordia University, Montreal, Canada

A new current-fed topology for wireless inductive power transfer (IPT) application using half-bridge circuit is proposed and analyzed. Conventional IPT circuits employ parallel L-C resonant tank/compensation network to transfer power effectively through air-gap. However, in medium power application, this topology suffers from a major drawback that the voltage stress across the inverter switches are considerably high due to high reactive power consumed by the loosely coupled coil. In the proposed topology, his is mitigated by adding a properly designed capacitor in series with the coils. During grid-to-vehicle (G2V) operation, the power flow is controlled through variable switching frequency modulation to achieve extended ZVS of the inverter switches. For G2V operation, the converter circuit is analyzed and simulated using PSIM 9.3. Analytical and simulation results are verified through experimental results obtained by testing a 1.2kW lab-prototype.

**9:45AM***Reduction on Radiation Noise Level for Inductive Power Transfer Systems with Spread Spectrum focusing on Combined Impedance of Coils and Capacitors [#308]*  
Kent Inoue, Keisuke Kusaka and Jun-ichi Itoh   
, Nagaoka University of Technology, Japan

Two reduction methods on radiation noise of inductive power transfer (IPT) systems are proposed and experimentally demonstrated. In the IPT systems for electrical vehicles (EVs) or plug-in hybrid electrical vehicles (PHEVs), noise reduction technologies are strongly required because the radiation noise from the IPT system for EVs or PHEVs must not exceeds the limits on standards; for example the regulation by CISPR is well-known regulation. The proposed method suppresses the radiation noise using spread spectrum technique. The radiation noise from the transmission coils of the IPT system is spread in a frequency domain by changing the output frequency of an inverter at random. The output frequency is selected according to pseudo random numbers. The first proposed method; a spread spectrum with a uniform distribution (SSUD), evenly selects the output frequency within 80 kHz to 90 kHz. Another method; a spread spectrum with a biased distribution (SSBD) is focusing on the output current of the inverter. The possibility for the select of output frequency is biased in proportion to a combined impedance of the transmission coil and the resonance capacitors. In the experiments with an output power of 3 kW, the fundamental components are suppressed by 42.6% and 72.1% by applying the SSUD and the SSBD in comparison with the conventional system, which operates the inverter at a fixed frequency.

Modeling and Control of DC-DC Converters II

Wednesday, September 21, 8:30AM-10:10AM, Room: 102C, Chair: Reza Sabzehgar, Liuchen Chang

**8:30AM***A New High-Frequency Simulation Model for Multi-Winding Transformers used in Switched-Mode Power Supplies [#165]*  
Ripunjoy Phukan, Lakshmi Ravi, Amirhossein Shahirinia and Rangarajan Tallam   
, Georgia Institute of Technology, Atlanta GA, United States; Rockwell Automation, Mequon WI, United States; Alfred University, Alfred NY, United States

In this paper, a new high-frequency simulation model for multi-winding transformers used in switched-mode power supplies (SMPS) is presented. The model can be constructed from simple impedance measurements on a transformer and using information that can typically be found on component datasheets. The model can be applied to the design of an SMPS to determine peak voltage and current stress on the switching device, and to predict conducted emissions for electro-magnetic compatibility (EMC). The model can be implemented through any commercially available circuit simulation package. Simulation and experimental results obtained on a high-voltage one-switch and two-switch Flyback SMPS are provided to validate the modeling method.

**8:55AM***Multi-Phase Sliding Mode Control for Chattering Suppression in a DC-DC Converter [#1476]*  
Woonki Na, Pengyuan Chen, Harkamal Singh and Jonghoon Kim   
, Cal St Univ-Fresno, United States; Chosun University, Korea (South)

This paper presents a Multi-Phase Sliding Mode(MPSM) Control Strategy for solving chattering issues inherently existing in DC-DC converters. The main idea of the proposed methodology is to implement a MPSM Control for geometrically nullifying the amplitude of ripple currents yielded by the switching patterns. The benefits of the proposed Multi-Phase Sliding Mode Control strategy involve low-switching frequency contributing to reduce switching power loss and leading to simplification of circuit topology. Throughout the experimental implementation, the concepts of control strategies were validated and the advantages of the proposed strategy were confirmed such as low-switching power loss, and simple circuit structure compared to traditional multi-phase SMC implementations.

**9:20AM***Gradient-reference-current Control of Tri-state Buck Converter to Improve Dynamic Response over Wide Load Range [#361]*  
Shuhan Liao, Xiaoming Zha, Fei Liu, Wenjun Liu and Kun Feng   
, Wuhan University, China

Gradient-reference-current (GRC) control strategy is proposed to achieve better dynamic response for tri-state buck converter over a wide load variety without additional hardware. By designing the logical current comparing element without load current detection, the conduction mode of tri-state buck converter under GRC control could be switched between discontinuous conduction mode (DCM) and pseudo continuous conduction mode (PCCM) adaptively to avoid large ripple voltage when converter operates over wide load range. As it operates in load condition within a comparatively small range, the converter stays operating in PCCM and the reference current could be changed in the same trend with load current among the pre-set values to improve the efficiency of tri-state buck converter in light load condition and the dynamic performance of it in heavy load condition. Simulation results verify the effectiveness of GRC control strategy.

**9:45AM***A Control Strategy for Paralleled Bi-Directional DC-DC Converters Used in Energy Storage Systems [#212]*  
Zhenya Zhang, Zhao Zhang, Shaojun Xie and Chen Yang   
, Nanjing University of Aero. and Astronautics, China

According to the control requirements of modular power used in energy storage systems, a parallel control strategy for bi-directional DC-DC converter is proposed and applied to the bi-directional DC-DC converter combined by current-fed half bridge and voltage- fed half bridge. While converters operate in parallel, the master-slave control based on digital communications can solve the problem of unequal current distribution caused by different parasitic parameters between parallel modules, and the strategy is with strong anti-interference ability. When running, each slave module will modify the reference of its own internal current loop by comparing its bus side current with the master module's bus side current via its current-sharing loop, so that the current sharing at the DC bus side can be achieved. Meanwhile, with the auto-master-selected strategy, a new master module will arise immediately when the former master module fails, which solves the problem of system failure when master module breaks down with traditional master-salve control. The simulation and experimental results prove the validity of the parallel control strategy.

Modulation Techniques II

Wednesday, September 21, 8:30AM-10:10AM, Room: 102E, Chair: Madhu Sudhan Chinthavali, Sufei Li

**8:30AM***Steady-State Analysis of the Phase Shift Modulated LLC Resonant Converter [#269]*  
Wei Liu, Binbin Wang, Wenxi Yao, Zhengyu Lu and Xiaoyi Xu   
, Zhejiang University, China; State Grid Nantong Supply Company, China

In many applications, phase shift modulation (PSM) has been proven to be a promising supplement of pulse frequency modulation (PFM) in LLC resonant converter. However, steady-state analysis of PSM LLC converter is not thoroughly studied yet. This paper presents a generalized PSM LLC model which can provide accurate prediction on resonant voltage and current behavior, dc gain and all the other steady-state information. Then, operation modes, mode boundaries and distribution are discussed with three cases according to the relationship between switching frequency and resonant frequency. Meanwhile, dc voltage gain and zero-voltage switching characteristics of each operation mode are briefly analyzed. Simulation results verify the accuracy of proposed analysis.

**8:55AM***Practical Implementation of Global Synchronous Pulse Width Modulation with Time Delay Compensation and Distributed Calculation Capabilities [#934]*  
Tao Xu, Feng Gao and Liwei Zhou   
, Shandong University, China

The distributed inverters are integrated into grid without coordinated PWM and the switching ripples of inverters are randomly accumulated at point of common coupling (PCC). Global synchronous pulse width modulation (GSPWM) can attenuate the accumulated switching ripples. This paper proposes time compensation method which compensates the time delay of synchronization signals for inverters in distance. Then, this paper proposes distributed calculation method for optimal phase shift and synchronization frequency in large-scale application. This new method is much faster than before. Finally, Matlab simulations and experimental results are presents to verify the performance of proposed methods.

**9:20AM***Research on Zero-Sequence Circulating Currents in Parallel Three-Level Grid-Tied Photovoltaic inverters [#185]*  
Yang Li, Xu Yang, Wenjie Chen and Zhang Feng   
, Xi'an Jiaotong University,EE, China

This paper proposes a parallel-connected system where two three-phase three-level T-Type photovoltaic inverters with common ac and dc sides to improve the power rating. However, zero-sequence circulating currents (ZSCCs) will occur, which will distort currents, decrease efficiency, and increase loss. In this paper, the fundamental mechanism of ZSCCs based on the derived model of ZSCCs is analyzed in details including the dead time effects. It is can be seen that the ZSCCs generated in three-level case are more complex than parallel two-level inverters due to existing more space vectors. Then, a synchroniz-ing starting small vector control method with PI controller and feedforward control method is proposed to suppress the ZSCCs. As a result, a good circulating current suppression performance can be obtained. The effectiveness of the analysis and proposed method is validated by experimental results.

**9:45AM***Modified Pulse Energy Modulation Technique of a Three-Switch Buck-Boost Inverter [#26]*  
Shuang Xu, Riming Shao, Liuchen Chang and Shuying Yang   
, University of New Brunswick, Canada; Hefei University of Technology, China

This paper proposed a modified pulse energy modulation (PEM) technique for a single-phase single-stage three-switch buck-boost inverter, solving the issue existed in practical applications that the requirement for sampling circuits is too high to achieve. The three-switch buck-boost inverter was investigated for both standalone and grid-connected operations. Simulation and experimental results verified that the newly proposed PEM technique enables the buck-boost inverter to transfer the demanded energy from a DC source to AC side and achieve a sinusoidal output current with low total harmonic distortion (THD). Therefore, it can be concluded that the proposed modified PEM technique is suited for buck-boost inverters in distributed generation systems, with lower requirement for the sampling circuits. The new contributions presented in this paper include advancing the PEM concept as an alternative to PWM for inverter modulations; and applying the proposed PEM technique to a low component-count inverter in standalone and grid-connected applications.

Modeling, Control and Stability of Modular Multilevel Converters

Wednesday, September 21, 8:30AM-10:10AM, Room: 202E, Chair: Rik De Doncker, Pragasen Pillay

**8:30AM***MMC-HVDC: Simulation and Control Strategy [#808]*  
Suman Debnath and Madhusudhan Chinthavali   
, Oak Ridge National Laboratory, United States

Simulation of modular multilevel converter (MMC) based high-voltage direct current (HVDC) systems assumes significance due to their growing popularity. It could assist with the design of hardware, control systems of MMC and HVDC networks, and power system topology. However, simulation of MMC-HVDC using existing software takes a long time due to the presence of a large number of states and non-linear devices. This paper presents an ultra-fast single- or multi-CPU simulation algorithm to simulate the MMC-HVDC system based on state-space models and using hybrid discretization algorithm with a relaxation technique that reduces the imposed computational burden. Using the developed simulation algorithm, a control system is developed for an MMC-HVDC system that reduces the switching losses in the system.

**8:55AM***Hybrid Railway Power Conditioner Based on Half-Bridge Modular Multilevel Converter [#416]*  
Li Liu and NingYi Dai   
, University of Macau, Macau

Hybrid railway power conditioner (HRPC) has been applied to compensating negative-sequence current, reactive power and harmonics in a traction power supply system. Single-phase back-to-back converter is used to implement power conditioning in a HRPC. Its operational voltage is lower than a conventional RPC since it is coupled to 25 kV feeder via a LC branch. However, multilevel converter was not used which is necessary if the HRPC is coupled to the feeder without transformer. A HRPC based on single-phase half-bridge back-to-back modular multilevel converter (MMC) is proposed in this paper. The center-split point of the DC bus is connected to one phase and provides compensating current. Since direct current tracking with hysteresis PWM is not applicable to MMC, proportional-integral (PI) current controller is selected to generate voltage reference. The circulating current is analyzed in detail and parameter design of the MMC is presented. The cell voltage balancing and dc bus voltage balancing of the MMC are studied. Simulation results are provided to verify the effectiveness of the proposed HRPC with its control method.

**9:20AM***A PWM Method Reducing Harmonics of Two Interleaved Converters [#926]*  
Jaejin Han, Younggi Lee and Seung-Ki Sul   
, Seoul National University, Korea (South)

This paper proposes a PWM method reducing harmonics of two interleaved converters at twice the switching frequency region. If harmonics at twice the switching frequency region can be reduced by the PWM method, the size of filter interfacing the grid and converter would be reduced. Based on Fourier series of phase voltage in every switching period, offset voltage for PWM minimizing harmonics at twice the switching frequency region can be calculated in real time. With the proposed PWM, the size and volume of inductive filters of two interleaved parallel converters can be shrunken conspicuously. Effectiveness of the proposed method is verified by the computer simulation and experimental results. The maximum harmonic at twice the switching frequency region has been reduced by 58% at modulation index 0.8.

**9:45AM***DC Impedance Modeling and Stability Analysis of Modular Multilevel Converter for MVDC Application [#833]*  
Ran Mo, Qing Ye and Hui Li   
, Florida State University, United States

Modular multilevel converter (MMC) is a promising converter topology to be applied in medium-voltage dc (MVDC) system due to its advantages of superior fault response, high quality output voltage and high efficiency. This paper is focused on the analysis of the features of MMC dc impedance in MVDC system and its influence on MVDC system stability. First, the closed-loop terminal impedance of a MMC at the dc output side is derived and verified by compared with that measured through a circuit-based model. It is also found that the capacitor size and dynamic will not affect the MMC impedance if the capacitor is designed to limit up to 20% voltage ripple, which will simplify the stability analysis. A shipboard MVDC system consisting of a MMC and other load converters has been established. All the impedance characteristics of load converters and their mutual interactions with the MMC are explored. With the developed MMC dc impedance and stability analysis method, the MVDC system stability characteristics can be predicted, which can be used for system design to maintain stability. The simulation results are consistent with the analysis.

Reluctance Machines II

Wednesday, September 21, 8:30AM-10:10AM, Room: 102B, Chair: Babak Fahimi, Sufei Li

**8:30AM***Segmented Rotor Design of Concentrated Wound Switched Reluctance Motor (SRM) for Torque Ripple Minimization [#464]*  
Md Ashfanoor Kabir and Iqbal Husain   
, North Carolina State University, United States; North Carolina State Unievrsity, United States

Torque ripple minimization of concentrated wound segmented rotor SRM is achieved through rotor segment designs. Compared to existing ripple minimization techniques the proposed method does not require current profiling, controller complexity or additional converter components. First, an FEA based semi-numerical machine model is developed to identify the torque ripple sources. Next, a new design of rotor segment is presented with segmented dip to effectively minimize torque ripple. Effect of different rotor design parameters on machine performance are studied. Both one factor at a time and multi-dimensional, multi-objective optimization of design parameters are performed to evaluate their performances. The optimized design can reduce torque ripple by 29 percent which is a significant improvement considering the simplicity of this method.

**8:55AM***Extending the Speed Range of A Switched Reluctance Motor using a Fast Demagnetizing Technique [#1267]*  
Mohamad Abd Elmutalab, Elrayyah Ali, Tausif Husain and Yilmaz Sozer   
, University of Akron, United States; Qatar Environmental and Energy Research Inst, Qatar

In this paper, a switched reluctance motor (SRM) with an auto-transformer like winding in each phase is presented. The new winding structure allows for fast demagnetization, which enhances the machine performance at high speeds. During demagnetization, the DC bus voltage is applied across a portion of the phase winding and accordingly, a higher negative demagnetization voltage/turn is applied, which leads to an increment in the discharge rate for the phase excitation currents. The proposed concept is verified through Finite Element Analysis (FEA) circuit simulations on a case study motor. The power electronic converters that can be used with the proposed winding configuration and its associated control have been investigated.

**9:20AM***Development and Analysis of U-core Switched Reluctance Machine [#395]*  
Rasmus Jaeger, Simon Staal Nielsen, Kristian Kongerslev and Peter Omand Rasmussen   
, Aalborg University, Denmark; Hydratech Industries, Denmark

Switched reluctance machines (SRMs) have seen a lot of interest due to their rugged and fault tolerant construction as well as their high efficiency over a wide speed range. The technology however suffers from torque ripple, acoustic noise and low torque density. Many concepts to address these disadvantages have been presented, but not all of them have been demonstrated practically. This paper presents a practical demonstration and assessment of a segmented U-core SRM, which copes with some of the disadvantages of the regular SRM. The U-core SRM has a segmented stator, with a short flux path and reduced flux reversal, reducing core losses. Due to an increased number of poles, torque density is increased and torque ripple reduced. A prototype is built and through a number of tests, the machine is mapped and all loss components are analysed. As a result of the analysis, an assessment is presented, which addresses the shortcomings of the U-core technology, as well as general considerations for SRMs. This allows for further development and improvement of the technology, and also contributes to improve the development and modelling of conventional SRMs.

**9:45AM***Torque Ripple and Acoustic Noise of Current Modulations of a Pseudo-Sinusoidal Switched Reluctance Motor [#1282]*  
Qingqing Ma, Lanhua Zhang, Xiaonan Zhao, Xuesen Cui and Jih-Sheng Lai   
, Virginia Tech, United States; North China Electric Power University, China

Torque ripple and acoustic noise are two major drawbacks to switched reluctance motors. The abrupt change of phase current is main cause of acoustic noise, while both commutation and current wave shape are two major factors contributing to high torque ripple. In order to simultaneously reduce torque ripple and noise, a specific current modulation based on real inductance profile can be employed to recently proposed pseudo-sinusoidal switched reluctance motor (PSSRM). Performance comparison including torque ripple, acoustic noise and efficiency with conventional square and half-sine current modulations are investigated. The performance of the specific current modulation is verified by simulations and experiments with a 12/16, three phase 0.4-hp PSSRM. The results show torque ripple and acoustic noise can be simultaneously reduced with a comparable efficiency by the proposed current modulation method.

PM Machines I

Wednesday, September 21, 8:30AM-10:10AM, Room: 101A, Chair: Ayman El-Refaie, Ali Bazzi

**8:30AM***Proposal of Electrically Reversal Magnetic Pole Type Variable Magnetic Flux PM Motor [#606]*  
Masahiro Aoyama, Kazukiyo Nakajima and Toshihiko Noguchi   
, SUZUKI Motor Corporation, Japan; Shizuoka University, Japan

This paper describes a variable magnetic flux PM motor in which space harmonic power is utilized for the magnetic flux weakening, automatically. The stator has a toroidally-concentrated winding structure, and the torque generation surfaces are composed of three air-gaps which are single radial-gap and double axial-gaps. The radial-gap rotor is a consist-magnetized PM rotor and the axial- gap rotors are self-excited wound-field rotor. The axial-gap rotor can retrieve a space harmonic power, which is inevitabley generated by a concentrated winding structure, for magnetomotive force. A mechanical design of the prototype is revealed, and the operation principle of the automated-magnetic flux weakening is clarified through the FE-analysis. In addition, actual prototype machine is introduced, and preliminary experimental test for the verification of self-exitation is demonstrated. Consequently, the effect of automated-armature line voltage decrease is investigated with respect to rotation speed increase.

**8:55AM***Torque and Core Loss Characterization of a Variable-Flux Permanent-Magnet Machine [#1433]*  
Chirag Desai and Pragasen Pillay   
, Concordia University, Canada

An appropriate torque-angle selection can improve the torque-to-current ratio of a machine, the size of the converter, and provide an optimal operation of the motor. An accurate determination of the core loss will lead to a better machine design and efficiency estimation. This paper presents the torque-angle and core loss characterization of a variable-flux permanent-magnet machine. Torque-angle curves and core losses are measured and simulated for a 7.5 hp variable-flux machine. The core losses are also obtained using an analytical method. The experimental results for torque-angle and core losses are found to be in good agreement with the simulations and the core losses are also in correlation with analytical data.

**9:20AM***Examination to Enhance Efficiency of V-shaped IPMSM Using Concentrated Winding Structure at High Speed and High Torque Area [#1513]*  
Ayato Nihonyanagi, Takemoto Takemoto, Satoshi Ogasawara, Naohiko Aoki and Kwansu Lee   
, Hokkaido University, Japan; LG Electronics JAPAN Lab. Inc., Japan

IPMSMs used for industrial applications generally require high efficiency operation in a certain operating point or area in addition to constant torque operation. In this research, the examined motor demands high efficiency operation at high speed and high torque area. In this case, the current phase angle is small and it is difficult to use reluctance torque effectively. Furthermore, concentrated winding structure has been adopted to cut manufacturing cost and to use limited space effectively. In general, IPMSMs using concentrated winding structure have a difficulty of generating reluctance torque from the perspective of getting q-axis armature reaction magnetic flux. In this paper, to enhance the efficiency of V-shaped IPMSM using concentrated winding structure at high speed and high torque area, the rotor structures which effectively use permanent magnet torque have been examined. Analysis result of 2D-FEA shows that the examined rotor structure, which arranges disproportional gap and large flux barrier on the q-axis magnetic flux path, can enhance the efficiency at high speed and high torque by suppressing the q-axis magnetic flux and by concentrating the field magnetic flux of PMs on the d-axis.

**9:45AM***Advanced High Torque Density Non-overlapping Winding PM Vernier Machines [#263]*  
Tianjie Zou, Dawei Li, Ronghai Qu, Jian Li and Dong Jiang   
, Huazhong University of Science and Technology, China

In recent years, permanent magnet (PM) vernier machines have gained more and more attentions due to their high torque density and simple mechanical structure. However, vernier PM machines with lap windings always suffer from long end winding length, and regular non-overlapping winding may result in torque reduction for PM vernier (PMV) machines. In this paper, an advanced PM vernier (APMV) machine topology with multi working permeance harmonics is proposed. This topology is equipped with non- overlapping winding, i.e. short end winding length, and could achieve 20% higher torque density than that of regular non-overlapping winding PMV machine, with the same magnet usage. Furthermore, both the theoretical analysis and finite element algorithm (FEA) are used to study the performances of this topology, such as back EMF, output torque as well as structure parameter effect. Finally, analysis results are verified by experimental test on a 21Nm prototype, which is designed to have similar volume and weight with a 14Nm regular commercial PM machine.

Drive/Utility Interface

Wednesday, September 21, 8:30AM-10:10AM, Room: 101B, Chair: Wenping Cao, Shih-Chin Yang

**8:30AM***Synchronous Switching of Non-Line-Start Permanent Magnet Synchronous Machines between Inverter and Grid Drives [#92]*  
Ronggang Ni, Dianguo Xu, Frede Blaabjerg, Gaolin Wang, Binbin Li and Kaiyuan Lu   
, Harbin Institute of Technology, China; Aalborg University, Denmark

Compared with Induction Machines (IMs) or Line-Start Permanent Magnet Synchronous Machines (LSPMSMs), Non-Line-Start Permanent Magnet Synchronous Machines (NLSPMSMs) have higher efficiency and better dynamic performance. However, NLSPMSMs have no damping windings in the rotor and hence cannot start themselves directly to the grid drive. For applications where a constant speed drive instead of Variable Speed Drive (VSD) is preferred, NLSPMSMs are required to be driven by the grid. Therefore, inverter aided soft startup and soft stop of such kind of motors are necessary. In this paper, a modified method of switching NLSPMSMs from inverter to grid mode drives, which is named as "forward switching" is proposed by introducing an additional V/f control after phase tracking in order to achieve voltage magnitude tracking. Furthermore, the method of switching the NLSPMSMs from grid to inverter drives, which is named as "backward switching" is also proposed. No position sensors are used for the consideration of low cost and high reliability, and the extended ElectroMotive Force (EMF) based position sensorless control algorithm is adopted during inverter drive. With the help of additional V/f control during switching, the current peak can be reduced for smooth switching. Experiments on an 18.5 kW NLSPMSM prototype are carried out to verify the effectiveness of the proposed methods.

**8:55AM***Instability Detection and Protection Scheme for Efficiency Optimized V/f Driven Synchronous Reluctance Motors (SynRM) [#778]*  
Sara Ahmed, Gholamreza Jalali, Zach Pan and Hongrae Kim   
, Virginia Polytechnic Institute and State Univers, United States; North Carolina State University, United States; ABB Inc., United States

This paper introduces a new method to stabilize synchronous reluctance motors (SynRMs) driven by efficiency optimized V/f control utilizing optimized flux. Efficiency optimized V/f driven SynRMs are prone to instabilities. Specifically, it becomes unstable for either fast ramp acceleration or large load disturbances. For example, in an efficiency optimized V/f control scheme, flux is reduced under low load to improve efficiency. However, a large load increase would lead to loss of synchronization under this condition. In this paper, a stability analysis of efficiency optimized V/f driven SynRM is performed. Instability threshold indicators using power factor and stator current angle are proposed. A novel instability protection scheme is introduced and verified in experiment.

**9:20AM***Power-Quality-Oriented Optimization in Multiple Three-Phase Adjustable Speed Drives [#1500]*  
Yongheng Yang, Pooya Davari, Frede Blaabjerg and Firuz Zare   
, Aalborg University, Denmark; The University of Queensland, Australia

As an almost standardized configuration, Diode Rectifiers (DRs) and Silicon- Controlled Rectifiers (SCRs) are commonly employed as the front-end topology in three-phase Adjustable Speed Drive (ASD) systems. Features of this ASD configuration include: structural and control simplicity, small volume, low cost, and high reliability during operation. Yet, DRs and SCRs bring harmonic distortions in the mains and thus lowering the overall efficiency. Power quality standards/rules are thus released. For multiple ASD systems, certain harmonics of the total grid current can be mitigated by phase-shifting the currents drawn by SCR-fed drives, and thus it is much flexible to reduce the Total Harmonic Distortion (THD) level in such applications. However, the effectiveness of this harmonic mitigation scheme for multiple ASD systems depends on: a) the number of parallel drives, b) the power levels, and c) the phase-shifts (i.e., firing angles) for the corresponding SCR-fed drives. This paper thus adopts a particle swarm optimization algorithm to optimize the power levels and the firing angles for multi-drive systems considering a fixed number of drives when practically implemented. The optimization is done to minimize the THD level of the total current at the point of common coupling. Simulations with the optimized results are carried out and laboratory tests on a two-drive system are provided to demonstrate the phase-shifting harmonic mitigation scheme. Issues concerning the practical implementation of the optimal results in multi-drive systems are also addressed.

**9:45AM***A Four-Quadrant Permanent Magnet Synchronous Machine Drive with a Tiny DC Link Capacitor [#809]*  
Mahima Gupta and Giri Venkataramanan   
, University of Wisconsin - Madison, United States

Three phase ac drives using a dc link typically feature a significant amount of dc energy storage to maintain a stiff dc bus. This paper examines the concept of reducing the size of the dc link capacitor dramatically, to store just enough energy to provide one high frequency switching cycle of output power. The dc bus is no longer stiff and hence the classical sinusoidal pulse width modulation cannot be used. But, the stored energy modulation (SEM) concept that is used here synthesizes high quality sinusoidal waveforms even with such tiny dc link capacitors. In SEM, the switching intervals of the interconnecting switches are carefully determined non-linear functions of various operating parameters such as reactive component sizing, switching frequency, load levels, etc. The detailed operation of the SEM modulated converter for a field-oriented controlled (FOC) four-quadrant permanent magnet synchronous machine (PMSM) electric drive application using space vector modulation (SVM) has been presented in the paper. The paper also includes circuit simulation results and preliminary design considerations of a SEM modulated drive.

PM and IPM Motor Drives II

Wednesday, September 21, 8:30AM-10:10AM, Room: 101CD, Chair: Omer Onar, Rakib Islam

**8:30AM***Effect of Position Sensor error on the Performance of IPMSM drives [#1272]*  
Ramakrishnan Raja, Tomy Sebastian, Mengqi Wang, Mohammad Islam and Abraham Gebregergis   
, Halla Mechatronics, Bay City , Michigan, United States; University of Michigan-Dearborn,Michigan, United States

Accurate knowledge of motor position is required in the motor drive application where smooth torque performance is needed. The error in position causes ripple in the developed current and thereby produce torque ripple. This paper analyzes the various effects of position sensor error in the current developed and in the torque generated in a current controlled Permanent Magnet Synchronous Motor drive. This research is focused on analyzing effect of position error on smooth production of torque in an IPMSM drive due to various inaccuracies. The analysis is verified through simulation and test results by measuring torque and torque ripple performances of a IPMSM drive.The results can be easily extended to SPM drive also.

**8:55AM***Signal-Injection-Aided Position and Speed Estimation for PMSM Drives with Low-Resolution Position Sensors [#1070]*  
Giulio De Donato, Giacomo Scelba, Mario Pulvirenti, Giuseppe Scarcella and Fabio Giulii Capponi   
, University of Rome - La Sapienza, Italy; University of Catania, Italy; University of Catania, Italy; university of Rome - La Sapienza, Italy

The aim of this paper is to reduce the low-speed limitation of PMSM drives that use low-resolution position sensors. It is recognized, for the first time, that this may be overcome by merging signal-injection-based self-sensing and low-resolution sensor technologies, if the machine possesses a detectable amount of electromagnetic saliency. The supplementary information coming from the injection of an additional high frequency magnetic field may be used to aid the low-resolution-based position and speed estimation algorithm, significantly improving the low-speed performance of the drive. In this research contribution, the quantization-harmonic decoupling vector-tracking observer is used for speed and position estimation. It is shown how this algorithm can be easily integrated with any high frequency signal injection method. Extensive experimental results are provided demonstrating the significant performance improvements at low speeds for a PMSM drive using 1, 2 and 3 bit-per-pole-pair sensing systems, when signal injection is used to aid position and speed estimation.

**9:20AM***Integrated Switch Current Sensor for Shortcircuit Protection and Current Control of 1.7-kV SiC MOSFET Modules [#1512]*  
Jun Wang, Zhiyu Shen, Rolando Burgos and Dushan Boroyevich   
, Center for Power Electronics Systems (CPES), United States

This paper presents design and implementations of a switch current sensor based on Rogowski coils. The current sensor is designed to address the issue of using desaturation circuit to protect the SiC MOSFET during shortcircuit. Specifications are given to meet the application requirement for SiC MOSFETs. It is also designed for high accuracy and high bandwidth for converter current control. PCB-based winding and shielding layout is proposed to minimize the noises caused by the high dv/dt at switching. The coil on PCB are modeled by impedance measurement, thus the bandwidth of coil is calculated. At the end, various test results are demonstrated to validate the great performance of the switch current sensor.

**9:45AM***Current Reconstruction Method for PMSM Drive System with a DC Link Shunt Resistor [#337]*  
Han-Beom Yeom, Hyun-Keun Ku and Jang-Mok Kim   
, LG Electronics, Korea (South); Pusan National University, Korea (South)

For the cost reduction of the inverter system, a DC link shunt resistor can be used to obtain the phase current of the AC motor. However, the phase current cannot be obtained from the shunt resistor when the duration of the active vector is shorter than the minimum time to sample the DC link current accurately. Conventional methods to reconstruct the phase current have some problems such as the high THD (Total Harmonic Distortion), the acoustic noise and the inaccurate reconstruction of the phase current in the low modulation region. In this paper, the cause of the noise in the conventional method is analyzed. To solve the acoustic noise problem, current reconstruction method based on current estimation is proposed. Intermittent PWM shift method is also proposed to enhance the accuracy of the reconstructed current in the low modulation region. The effectiveness of the proposed methods is verified through the simulations and the experiments. The usefulness of the proposed method is also proven by measuring the sound in the anechoic room.

Modeling of WBG Devices and Modules

Wednesday, September 21, 8:30AM-10:10AM, Room: 202C, Chair: Enrico Santi, Robert Pilawa-Podgurski

**8:30AM***PSpice Modeling Platform for SiC Power MOSFET Modules with Extensive Experimental Validation [#83]*  
Lorenzo Ceccarelli, Muhammad Nawaz and Francesco Iannuzzo   
, Aalborg University, Denmark; ABB Corporate Research Center, Sweden

The aim of this work is to present a PSpice implementation for a well- established and compact physics-based SiC MOSFET model, including a fast, experimental-based parameter extraction procedure in a MATLAB GUI environment. The model, originally meant for single-die devices, has been used to simulate the performance of high current rating (above 100 A), multi-chip SiC MOSFET modules both for static and switching behavior. Therefore, the simulation results have been validated experimentally in a wide range of operating conditions, including high temperatures, gate resistance and stray elements. The whole process has been repeated for three different modules with voltage rating of 1.2 kV and 1.7 kV, manufactured by three different companies. Lastly, a parallel connection of two modules of the same type has been performed in order to observe the unbalancing and mismatches experimentally, and to verify the model effectiveness in such challenging topologies.

**8:55AM***Development of Simulink-Based SiC MOSFET Modeling Platform for Series Connected Devices [#96]*  
Georgios Tsolaridis, Kalle Ilves, Paula Diaz Reigoza, Muhammad Nawaz and Francesco Iannuzzo   
, ABB Corporate Research Center, Sweden; Aalborg University, Denmark

A new MATLAB/Simulink-based modeling platform has been developed for SiC MOSFET power modules. The modeling platform describes the electrical behavior of a single 1.2 kV 350 A SiC MOSFET power module, as well as the series connection of two of them. A fast parameter initialization is followed by an optimization process to facilitate the extraction of the model parameters in a more automated way relying on a small number of experimental waveforms. Through extensive experimental work, it is shown that the model accurately predicts both static and dynamic performances.

**9:20AM***An Accurate Subcircuit Model of SiC Half Bridge Module for Switching Loss Optimization [#299]*  
Pengfei Tu, Shan Yin, Peng Wang, King Jet Tseng, Chen Qi, Xiaolei Hu, Michael Adam Zagrodnik and Rejeki Simanjorang   
, Nanyang Technological University, Singapore; Rolls-Royce Singapore Pte Ltd, Singapore

The increasing demand for high power density requires power converter to operate in high switching frequency. SiC power module is regarded as one of the most promising candidates for high-frequency applications due to the superior switching speed and low switching loss. The conventional strategy to optimize switching loss is normally achieved by repetitive double pulse tests, which is time-consuming to find an optimum gate resistance to achieve the trade-off between switching loss and EMI issues. In this work, an accurate SiC module subcircuit model is proposed. It considers the physical behavior of the device and can be directly extracted from the datasheet information. Good agreements are achieved between the PSpice simulation and experimental results in both switching waveform and switching loss. It also provides a guidance for gate driver design with a reasonable accuracy.

**9:45AM***Spatial Electro-Thermal Modeling and Simulation of Power Electronic Modules [#1068]*  
Christoph van der Broeck, Lukas Ruppert and Rik De Doncker   
, ISEA, RWTH Aachen University, Germany

In this work the spatial electro-thermal modeling of power electronic modules is discussed. It is shown how physical and mathematical modeling techniques can be combined to obtain a compact time efficient electro-thermal simulation framework for power electronic modules. The framework can be used to evaluate the transient temperature distribution of a power module in an electric vehicle over driving cycles. Based on the simulated temperature distribution the lifetime of the power module can be estimated using various aging laws. The simulation and lifetime estimation is demonstrated as an example for a Hybridpack2 inverter module. Finally, a design parameter study is carried out, which evaluates different module design options with respect to their impact on reliability.

Gate Drive Techniques II

Wednesday, September 21, 8:30AM-10:10AM, Room: 102A, Chair: Daniel Costinett, Pradeep S. Shenoy

**8:30AM***Automatic Optimization of IGBT Gate Driving Waveform Using Simulated Annealing for Programmable Gate Driver IC [#838]*  
Koutarou Miyazaki, Makoto Takamiya and Takayasu Sakurai   
, The University of Tokyo, Japan

Optimizing the gate driving waveform of power devices for energy loss and noise per switching has been attracting attention. This paper proposes a systematic method to automatically optimize the gate waveform by dynamically combining real measurements and software optimization loop based on simulated annealing algorithm. The method is applied to the turn-on and turn-off process of an IGBT double pulse test setup. A gate driving waveform with four time segments is employed for the optimization, which is realized by a help of a programmable gate driver IC. The machine-based optimization finishes within one and half hours and with the resultant optimized waveform, 59% energy loss decrease and 57% voltage overshoot reduction are achieved for the case of the IGBT turnoff compared with a simple single-step gate driving waveform.

**8:55AM***Active dv/dt Control of 600V GaN Transistors [#1250]*  
Bingyao Sun, Rolando Burgos, Xuning Zhang and Dushan Boroyevich   
, CPES-Virginia Tech, United States

With the fast-switching devices like GaN HEMT applying in power converters, the converters achieve higher switching frequency, higher efficiency and higher power density. As a result of the fast switching edge and high commutation speed, the issues like electromagnetic interference (EMI), overvoltage, gate protection become daunting tasks. The active gate control technique has been verified on the Si device to be an effective tool to relieve the challenges above, especially to reduce EMI noise by slowing down dv/dt with less penalty of switching loss. The paper proposes a new active dv/dt control circuit with fast response to change the 600 V GaN HEMT turn- off and turn-on dv/dt slew rate freely and independently, while the converter is running. To achieve this, simulations are first performed to verify the circuit function, considering all the possible parasitics distributed on the experimental setup, and a detailed circuit design is followed. Experimental results obtained on the 300V dc 15 A load current double pulse tester, composed by a GaN HEMT phase leg, validates the proposed method by varying turn-on dv/dt slew rate from 27.1 V/ns to 8.8 V/ns, turn-off dv/dt from 34.6 V/ns to 7.6 V/ns. Finally comparison with different gate resistors is provided, showing the proposed method has a smaller switching loss under the same dv/dt condition than using a large gate resistor.

**9:20AM***Commutation Strategies for Single-Chip Dual-Gate Bidirectional IGBTs in Matrix Converters [#1091]*  
Daming Wang, Sai Tang, Jun Wang, Zhengbin Xiong, Shanglin Mo, Xin Yin, Zhikang Shuai and Z. John Shen   
, Hunan University, China

This paper compares four different commutation strategies for a new monolithic dual-gate bidirectional IGBT (BD-IGBT) in matrix converters. A new variable-timing four-step commutation and an one-step commutation control strategies are proposed and compared with the conventional and the two-level four-step commutation methods reported previously. Operation modes and power losses of the BD-IGBT using these commutation strategies are analyzed with mixed-mode device/circuit simulation. The power loss and efficiency of a 13 kW three-phase to three-phase matrix converter are compared between the conventional combo switch and the new single-chip BD-IGBT implementations. It is found that the BD-IGBT, when using an optimal commutation strategy, offers significant advantages over the conventional IGBT/diode cell in terms of efficiency and cost.

**9:45AM***Two Comparison-Alternative High Temperature PCB-Embedded Transformer Designs for a 2 W Gate Driver Power Supply [#1248]*  
Bingyao Sun, Remi Perrin, Cyril Buttay, Bruno Allard, Nicolas Quentin, Rolando Burgos, Dushan Boroyevich and Marwan Ali   
, CPES-Virginia Tech, United States; Ampere lab - INSA Lyon, Univ. Lyon, France; Labinal Power Systems-SAFRAN, France

With fast power semiconductor devices based on GaN and SiC becoming more common, there is a need for improved driving circuits. Transformers with smaller inter-winding capacitance in the isolated gate drive power supply helps in reducing the conducted EMI emission from the power converter to auxiliary sources. This paper presents a transformer with a small volume, a low power loss and a small inter-capacitance in a gate drive power supply to fast switching devices, such as GaN HEMT and SiC MOSFET. The transformer core is embedded into PCB to increase the integration density. Two different transformer designs, the coplanar-winding PCB embedded transformer and the toroidal PCB embedded transformer, are presented and compared. The former has a 0.8 pF inter-capacitance and the latter has 85% efficiency with 73 W/in3 power density. Both designs are dedicated to a 2 W gate drive power supply for wide-band-gap device, which can operate at 200 degree Celsius ambient temperature.

Wireless Power Transfer III

Wednesday, September 21, 8:30AM-10:10AM, Room: 202B, Chair: Tsorng-Juu Liang, Khurram Afridi

**8:30AM***Performance Analysis of Magnetic Power Pads for Inductive Power Transfer Systems with Ferrite Structure Variation [#305]*  
Minkook Kim, Jongeun Byeon, Jae-Woo Lee and Byoung Kuk Lee   
, Sungkyunkwan University, Korea (South); LG Electronics, Korea (South)

In this paper, performance of rectangular shaped magnetic power pads for inductive power transfer (IPT) system according to the ferrite structure is analyzed. In order to evaluate the influences of ferrite structure, six cases of magnetic power pads are configured. Self-inductance, coupling coefficient, quality factor, and coil to coil efficiency are compared as the displacement increases in the direction of x or y axis. For accurate estimation, finite element method (FEM) simulation is used and loss components of the power pads are numerically calculated and considered. Through the simulation results, effectiveness of protrusive and enveloping ferrite structure is identified.

**8:55AM***Analysis of Mutually Decoupled Primary Coils for IPT Systems for EV Charging [#1362]*  
Seho Kim, Abiezer Tejeda, Grant Anthony Covic and John Talbot Boys   
, The University of Auckland, New Zealand

Inductive Power Transfer (IPT) systems have been proposed for various applications and have been increasingly gaining interest for electric vehicle (EV) charging. Numerous magnetic structures have been proposed for IPT systems for EV charging including structures involving mutually decoupled coils. This paper presents an analytical model of an IPT system composed of a two coil primary pad and a single coil secondary pad to show the importance of mutually decoupled coils in IPT systems using multi-coil primary pads. A controller is also proposed to find the optimal primary currents needed to achieve the "best" effective coupling factors at any secondary displacement for mutually decoupled primary coils. A 1.5 kW prototype system is implemented in the laboratory to validate the findings for ideally aligned and misaligned cases.

**9:20AM***Dynamic Matching System for Radio-Frequency Plasma Generation [#1261]*  
Anas Al Bastami, Alexander Jurkov, Parker Gould, Mitchell Hsing, Martin Schmidt and David Perreault   
, Massachusetts Institute of Technology, United States

Plasma generation systems represent a particularly challenging load for radio-frequency power amplifiers owing to the combination of high operating frequency (e.g., 13.56 MHz) and highly variable load parameters. We introduce a dynamic matching system for Inductively Coupled Plasma (ICP) generation that losslessly maintains near-constant driving point impedance (minimal reflected power) across the entire plasma operating range. This new system utilizes a Resistance Compression Network (RCN), an impedance transformation stage, and a specially-configured set of plasma drive coils to achieve rapid adjustment to plasma load variations. As compared to conventional matching techniques for plasma systems, the proposed approach has the benefit of relatively low cost and fast response, and does not require any moving components. We describe suitable coil geometries for the proposed system, and treat the design of the RCN and matching stages, including design options and tradeoffs. A prototype system is implemented and its operation is demonstrated with low pressure ICP discharges with O2, C4F8, and SF6 gases at 13.56 MHz and over the entire plasma operating range of up to 250 W.

**9:45AM***A Loosely Coupled Capacitive Power Transfer System with LC Compensation Circuit Topology [#48]*  
Hua Zhang, Fei Lu, Heath Hofmann, Weiguo Liu and Chris Mi   
, Northwestern Polytechnical University, China; University of Michigan, United States; San Diego State University, United States

This paper proposes a double-sided LC compensated capacitive power transfer (CPT) system, which is the dual of the conventional series-series (SS) compensated inductive power transfer (IPT) system. Four metal plates are arranged as the capacitive coupler, and there are coupling capacitances between each pair of plates. At each side, a compensation capacitor is connected in parallel with the plates, and its value is usually much larger than the coupling capacitance between the plates, which results in a loosely coupled CPT system. In this paper, the fundamental harmonics approximation (FHA) method is used to analyze the circuit working principle. It shows that the system can work at constant current mode. An expression for the system output power is expressed, which is similar to that of the SS compensated IPT system. A 150W input power CPT system is therefore designed as an example to validate the compensation topology. The experimental results show that the dc to dc efficiency of the system is 66.67% when the air-gap distance is 180 mm and the switching frequency is 1.5 MHz.

Wednesday, September 21, 10:30AM-12:10PM

Control for Photovoltaic Applications

Wednesday, September 21, 10:30AM-12:10PM, Room: 203AB, Chair: Martin Ordonez, Dezso Sera

**10:30AM***A Variable Step-Size MPPT for Sensorless Current Model Predictive Control for Photovoltaic Systems [#1613]*  
Morcos Metry, Mohammad B. Shadmand, Robert S. Balog and Haitham Abu-Rub   
, Texas A and M University, United States; Texas A and M University at Qatar, Qatar

Variability of the solar energy resources requires highly effective maximum power point tracking (MPPT) to ensure maximum energy harvesting from the photovoltaic (PV) modules. To accomplish this, a MPPT controller typically requires accurate knowledge of the voltage and current from the PV module, and must converge quickly with minimal hunting around the maximum power point (MPP). Conventional MPPT techniques use fixed step-size perturbation which need to be optimized for one of two objectives: reducing the convergence settling time, or reducing the steady state ripple. Also, the required sensors increase system cost and can cause reliability issues, particularly for the current sensors which can exhibit thermal drift and degrade over time. This paper presents a highly efficient, variable-step sensorless current MPPT controller using an observer-based model derived from the principles of model predictive control (MPC) to adaptively determine the perturbation step-size. The proposed variable step, sensorless current, model predictive control maximum power point tracking (VS-SC-MPC-MPPT) continuously adjusts the perturbation step size using the predicted dynamic model to enable fast convergence and small limit cycle, without the need of expensive measuring devices. The performance of the VS-SC-MPC-MPPT in this paper is compared to previously developed MPC-MPPT methods. The provided investigation aims to demonstrate higher system efficacy with lower cost. The feasibility of the proposed controller is verified though computer simulation and real time simulation using dSPACE DS1007.

**10:55AM***Study on the Unbalanced Current Injection Capability of Grid-Connected Photovoltaic Neutral-Point-Clamped Inverter [#1434]*  
Hossein Dehghani Tafti, Ali Iftekhar Maswood, Karthik Kandasamy, Ziyou Lim, Gabriel Ooi Heo Peng, Georgios Konstantinou and Josep Pou   
, Nanyang Technological University, Singapore; University of New South Wales, Australia

Due to high penetration of distributed generation units in power system, fault ride through (FRT) capability is one of the new requirements of the medium-scale grid-tied photovoltaic power plants (PVPPs). This paper proposes and investigates a control strategy for the neutral-point-clamped (NPC) inverter in order to inject proper unbalanced reactive currents to the grid during unbalanced grid faults. The proper unbalanced current injection reduces negative sequence of grid voltages and currents. The current references are scaled up/down individually, based on the grid phase rms voltages and inverter nominal current. The performance of the implemented control algorithm is investigated on a 150-kVA PVPP connected to 12.47-kV medium-voltage grid simulation model under various voltage sag conditions. Results from an experimental setup of grid-tied NPC inverter are presented in order to demonstrate the effectiveness of the proposed unbalanced current injection algorithm.

**11:20AM***Adaptive Dc Link Voltage Control Scheme for Single Phase Inverters with Dynamic Power Decoupling [#1162]*  
Yinglai Xia and Raja Ayyanar   
, Arizona State University, United States

Power density and efficiency are important metrics for power converters in many applications including renewable energy interface. Combined with the desire to replace the bulky, unreliable electrolytic dc link capacitors with film or ceramic capacitors due to reliability concerns, this has led to the trend of allowing increasingly higher double line frequency dc link voltage ripple. This paper discusses a scheme to improve the system overall efficiency by implementing an adaptive dc link voltage control scheme under different operating conditions for a recently introduced class of single phase inverter topologies that operate with very large dc link voltage ripple. The relationship between the minimum necessary dc link voltage for different input voltage, apparent power and power factor are analyzed and the optimal dc link voltage average value are derived analytically. The analysis and benefits of the proposed scheme are validated on a single-phase inverter hardware prototype employing SiC MOSFETs and DSP28335 for control implementation. The scheme can decrease the dc link voltage average value by 24.1% while decreasing the total loss of the inverter by around 20% compared to a design that does not use the adaptive dc link approach.

**11:45AM***ZVS Analysis and Power Flow Control for Three Limb Transformer Enabled SiC Mosfet Based Three Port DAB Integrating PV and Energy Storage(ES) [#1684]*  
Ritwik Chattopadhyay and Subhashish Bhattacharya   
, NCSU, United States

Multi-port dc-dc converters are the modular power electronic building blocks for integration of PV and Energy Storages(ES). The work in this paper focuses on ZVS characteristics for independent power flow control of three port DAB converter integrating PV and Energy Storage(ES), using three limb high frequency transformer. The independent power flow control discussed here, focuses on ES charging scenario for the converter using two different modulation techniques. ZVS scenario variations for two different modulation control technique for two different designs of three limb transformers, are discussed in the paper. A laboratory scale prototype using 1200V and 1700V SiC Mosfets has been made and preliminary results have been obtained for experimental validation of the ZVS scenarios.

Photovoltaic Characterization and Modeling

Wednesday, September 21, 10:30AM-12:10PM, Room: 203C, Chair: Tirthajyoti Sarkar, Ahmed Elasser

**10:30AM***A Rapid I-V Curve Generation for PV Model-based Solar Array Simulators [#437]*  
Young-Tae Seo, Jun-Young Park and Sung-Jin Choi   
, University of Ulsan, Korea, Republic of

Photovoltaic (PV) model can be a viable alternative to the conventional look-up- table as an accurate and versatile solar array simulator (SAS) engine. In PV model-based SAS, PV model has a critical role to generate appropriate I-V characteristic of the PV panel under rapidly varying temperature and irradiation, and its calculation speed as well as accuracy are key performances. In this paper, a novel algorithm that is suitable for such a SAS engine is proposed. The suggested method adopts conjugate gradient optimization to extract PV model parameters from the changing conditions and to reconstruct the exact I-V curve very rapidly. For the verification, the proposed algorithm is compared with conventional ones which have been widely used in the PV model extraction. As a result, the proposed model shows superior calculation speed with good accuracy.

**10:55AM***Photovoltaic Panel Simulation Based on Individual Cell Condition [#463]*  
Eduardo Abdon Sarquis Filho, Fabiano Fragoso Costa, Andre Pires Nobrega Tahim and Antonio Cezar de Castro Lima   
, Universidade Federal da Bahia, Brazil

The maximum power generated by a photovoltaic (PV) system depends on the intensity and uniformity of the irradiation over panels. The Maximum Power Point Tracking (MPPT) is a control technique used to adjust the operating voltage of PV panels in order to continuously harvest the maximum power available. Modeling of PV panel characteristic curves are useful for the evolution of MPPT control algorithms. However, most of simulation models are not capable of completely handling non-uniform irradiation, since they do not consider PV cells individually, and use simplified uniform approaches instead. This paper explains mislead estimation of maximum power point (MPP) caused by simplified approaches and proposes a new perspective to model PV panels based on individual cells' irradiation condition. The testing of shadow patterns demonstrates the importance of modeling cells individually in order to performan accurate MPP analysis. During the passing of shadows, the MPP voltage variation range can be over 39 times wider than the range predicted by simplified approaches. The proposed PV model is feasible and capable of provide a set of characteristic curves suitable for evaluating the MPPT algorithm efficiency.

**11:20AM***Development and implementation of a PV performance monitoring system based on inverter measurements [#960]*  
Sergiu Spataru, Anamaria Gavriluta, Lars Maaloe, Dezso Sera and Ole Winther   
, Aalborg University, Denmark; Technical University of Denmark, Denmark

Performance monitoring and fault detection systems are becoming more common in large photovoltaic (PV) plants as they can contribute to decreasing operation and maintenance costs, as well as for maximizing plant yield and lifetime. However, in case of residential and smaller commercial PV system applications the cost of the performance monitoring hardware and implementation is still high. Therefore, we present the practical development and implementation of a low-cost PV performance monitoring system for residential and commercial PV applications, based on the inverter's own monitoring and communication capabilities. The proposed monitoring system supervises the PV array maximum power and inverter energy production using performance models of the system, and is able to detect PV array and inverter level power loss and faults.

**11:45AM***Characterization of Silicon Based Photovoltaic Cells Using Broadband Impedance Spectroscopy [#43]*  
Olufemi Olayiwola and Paul Barendse   
, University of Cape Town, South Africa

The growth in photovoltaic installations makes characterization and condition monitoring essential. In this paper, broadband impedance spectroscopy is implemented for characterization and performance monitoring of silicon solar cells for near real-time operation. An optimized quasi-logarithmic broadband signal is designed to estimate the impedance response of the cells. Electrochemical equivalent circuits of the frequency response are then modelled from the obtained Nyquist plots and the cell parameters are extracted using complex nonlinear least squares. This procedure can be applied for direct estimation of the internal parameters of the silicon solar cells/module at different operating points. Results show that the implemented broadband characterization yields good correlation to the conventional electrochemical impedance spectroscopy at significantly reduced procedural time and equipment cost.

Utility Applications III

Wednesday, September 21, 10:30AM-12:10PM, Room: 202A, Chair: Srdjan Lukic, Deepak Divan

**10:30AM***DC Solid State Transformer Based on Input-Series-Output-Parallel Dual-Active-Bridge for MVDC Power Distribution [#719]*  
Biao Zhao, Qiang Song, Jianguo Li and Wenhua Liu   
, Tsinghua University, China; Tsinghua Univesity, China

Dc power transmission and distribution are becoming research hotspot all around the world, this paper presents dc solid state transformer (DCSST) will be the key device for dc power distribution to achieve flexible control and fast management of voltage and power between the medium/high voltage dc distribution grid and low voltage dc micro-grid. This discusses a high-frequency-link (HFL) isolated bidirectional DCSST scheme based on input-series-output- parallel dual-active bridge (DAB), and the topology, operation principle, control strategy, and experiments are present and analyzed. The proposed DCSST has the similar transmission power model with DAB. The series voltage balance and parallel power balance of DCSST can be achieved just by controlling series voltage balance. The experimental results verify the validity and effectiveness of proposed solution for MVDC power distribution.

**10:55AM***Six-Leg Single-Phase to Three-Phase Converter [#1088]*  
Nayara Brandao de Freitas, Cursino Brandao Jacobina, Ayslan Caisson Noroes Maia and Alexandre Cunha Oliveira   
, Federal University of Campina Grande, Brazil

This paper investigates the utilization of two different six-leg configurations of single-phase to three-phase converters. One of the topologies is transformerless and the other is transformer-based. The drive systems provide both bidirectional power flow and power factor control. Pulsewidth modulation techniques for the converter control are discussed. Simulation and experimental results are provided to illustrate and compare the operation of the systems.

**11:20AM***Flexible Transformers for Distribution Grid Control [#1398]*  
Hao Chen, Prasad Kandula, Anish Prasai, Joe Schatz and Deepak Divan   
, Georgia institute of technology, United States; Georgia Institute of Technology, United States; Varentec, Inc., United States; Southern Company, United States

This paper presents a novel device for distribution grid control. The proposed device, called flexible transformer, consists of a fractionally-rated converter and a slightly modified medium voltage (MV) distribution transformer with additional taps. The converter can be wired to either the primary or the secondary side of the transformer, resulting two different configurations. The proposed device successfully meets the requirements of great performance, long lifetime, high efficiency, and low cost for typical utility assets. This paper presents the concept of the flexible transformer as well as the schematic and operating principle of both configurations. Simulation and experimental results of the proposed device rated at 7.2 kV / 50 kVA is also provided.

**11:45AM***Comparative Analysis of Modular Multiport Power Electronic Transformer Topologies [#1601]*  
Mario Lopez, Fernando Briz, Mariam Saeed, Manuel Arias and Alberto Rodriguez   
, University of Oviedo, Spain

Conventional line-frequency transformers are a key element in the current power transmission system. Although they are a relatively cheap and well established technology, they are not able to provide new functionalities demanded by the power system operator. Solid State Transformers (SSTs), also called Power Electronic Transformers (PETs) are power electronics-based arrangements able to provide, in addition to the basic functions of a conventional transformer, new functionalities like harmonics, reactive power and imbalance compensation, and power flow control. This paper addresses a comparative analysis of modular PET topologies, including the popular CHB-based approach and MMC-based topologies. Criteria for the evaluation will include aspects like the number of cells required, ratings of the power devices, number and type of the PET ports and design requirements for passive elements.

Modeling, Analysis, and Control of Grid-Connected Converters II

Wednesday, September 21, 10:30AM-12:10PM, Room: 202D, Chair: Frede Blaabjerg, Rajendra Prasad Kandula

**10:30AM***Advanced Control of a High Power Converter Connected to Weak Grids [#984]*  
Shahparasti Mahdi, Catalan Pedro, Luna Alvaro, Candela Jose Ignacio and Rodriguez Pedro   
, Technical University of Catalonia, Spain; Ingeteam Power Technology, Spain

This paper addresses the stability problems of a high power converter connected to a weak grid. The wide range values that grid impedance can take, challenges the stability and the performance of the controllers, which are responsible of regulating the current injection in such converters. In this work, a control strategy based on stationary reference frame controllers is selected and implemented using a proportional resonant (PR) controller, with capacitor voltage feedforward and a phase shifter. As it will be demonstrated in this paper, although the feedforward contributes to enhance the transient response of the converter, it may cause also deep unstable dynamics near to the medium frequency and decreases the phase margin in low frequency ranges. Therefore, it can be used to damp the unstable dynamics near to resonance frequency range and the LCL-filter can be adopted for the high frequency one. In order to improve the controller performance, a new phase shifter is added to the control scheme to enhance the phase margin at low frequency ranges. Simulation and experimental results considering weak grid conditions are shown to validate the proposed method.

**10:55AM***A Power Density Optimization Method for a Power Pulsation Decoupling Buffer in Single-Phase DC-AC Converters [#1497]*  
Shibin Qin and Robert Pilawa-Podgurski   
, University of Illinois at Urbana-Champaign, United States

The goal of this work is to develop an analytical method to determine the optimum size of an active decoupling buffer in single phase DC-AC converters for the highest power density. The conventional method for active twice line frequency power pulsation decoupling is a structure commonly known as the full ripple port architecture. However, its high voltage stress and correspondingly large inductor volume become a bottleneck to improve its power density, and the large amount of power processed in the active converter increases the power losses, leading to large heat removal solutions. recently proposed series-stacked buffer architecture provides a way to reduce the buffer converter voltage stress, reduce the power conversion losses and balance the volume of passive components to achieve very high power density. This paper presents a design procedure of the series-stacked buffer architecture that optimizes the power density through mathematical derivations and numerical design examples. The design procedure is based on calculating the energy storage of the passive components as the optimization objective and analyzing the operation of the buffer converter that forms certain optimization constraints. A set of optimal design parameters is found by the method of Lagrange multipliers. A hardware prototype is developed under the guidance of this optimization and the high power density has been experimentally verified.

**11:20AM***Control Design in $$-Synthesis Framework for Grid-Connected Inverters with Higher Order Filters [#1568]*  
Nima Amouzegar Ashtiani, Mohsen Azizi and Sayed Ali Khajehoddin   
, University of Alberta, Canada; Michigan Technological University, United States

In this paper, a robust controller is designed based on $\mu$-synthesis method for grid-connected inverters. The performance of the controller is made robust against realistic uncertainties including the time delay and parameter changes, while the resonant oscillations are actively damped. The designed controller only relies on output feedback eliminating the need for extra feedback sensors that are normally used in full or partial state feedback systems. Simulation and experimental results confirm the satisfactory performance and robustness of the designed controller in both cases of a nominal system and a system with parameter variations.

**11:45AM***Sensorless Current Model Predictive Control for Maximum Power Point Tracking of Single-Phase subMultilevel Inverter for Photovoltaic Systems [#1618]*  
Morcos Metry, Sertac Bayhan, Mohammad B. Shadmand, Robert S. Balog and Haitham Abu-Rub   
, Texas A and M University, United States; Texas A and M University at Qatar, Qatar

Stochastic dynamic behavior of solar energy necessitates the use of robust controllers for photovoltaic (PV) power electronics interfaces to maximize the energy harvest by continuous operation at maximum power point (MPP). This paper proposes a sensorless current model predictive control maximum power point tracking (SC-MPC-MPPT) algorithm. By predicting the future behavior of the power conversion stage, the proposed controller features fast and stable performance under dynamic ambient condition and negligible oscillation around MPP at steady state. Moreover, it does not require expensive sensing and communication equipment and networks to directly measure the changing solar insolation level. The power conversion stage includes an upstream boost dc/dc power conversion to a dc-link capacitor, and a downstream seven-level sub-Multilevel Inverter (sMI) from the dc-link capacitor to the grid. The sMI is using three power arms cascaded with an H-bridge inverter. This topology brings considerable benefits such as reduced number of power switches and their gate drivers when compared to the traditional multilevel inverters. Model Predictive Control (MPC) is employed for current regulation of the sMI, thus eliminating the need of cascaded classical control loops and modulator. The proposed SC-MPC-MPPT technique for a boost converter is implemented experimentally using the dSPACE DS1007 platform.

DC Microgrids II

Wednesday, September 21, 10:30AM-12:10PM, Room: 203DE, Chair: Josep M. Guerrero, Ali Davoudi

**10:30AM***An Adaptive Power Distributed Control Method to Ensure Proportional Load Power Sharing in DC Microgrid Considering Equivalent Line Impedances [#824]*  
Duy-Hung Dam and Hong-Hee Lee   
, University of Ulsan, Korea (South)

This paper proposed a distributed control method for dc microgrid to ensure the proportional load sharing by taking into account the different line impedance. In the proposed method, the operation point of each DG is effectively defined based on the power rating and the instantaneous power of the DG to achieve the proportional load power sharing. A low bandwidth communication is used to transmit the data required to determine the power reference for all DGs. In order to balance the power per unit requirement, the output voltage of each DG is controlled by a power controller to adjust the desired operating point. Therefore, all DGs can operate at the balanced operating point on the droop curve to ensure the proportional load power sharing. This paper also considers the load shedding to prevent the dc microgrid from operating under overload condition. The effectiveness of the proposed method is verified by simulation and experiment which are carried out with 2.8kW prototype dc microgrid.

**10:55AM***The Performance of Polytopic Models in Smart DC Microgrids [#918]*  
Airan Frances, Rafael Asensi, Oscar Garcia, Roberto Prieto and Javier Uceda   
, Universidad Politecnica de Madrid, Spain

The huge progress of power electronics technology along last decades opens ex extraordinary new possibilities for the electric grid. Some examples of what ca can be achieved with the incorporation of electronic power converters in the sy system are the penetration of RS (renewable sources) and storage, boosting re reliability and power quality, and integrating consumers as part of the system. Ho However, there are still some challenges ahead before the massive deployment of Sm Smart Grids. Lately, a lot of research has been carried out on converters topologies and control strategies in order to get the most out of the microgrids. Therefore, there is a need for methodologies that allow designers to foresee the behavior of these systems comprised of several different power converters governed by the proposed control strategies. In this context, this paper studies the performance of the polytopic models for the analysis of commercial power converters working in dc microgrids. This is a nonlinear modeling technique which integrates small-signal models obtained in different operation points by means of suitable weighting functions. Furthermore, the linear local models can be obtained in a blackbox fashion using suitable two-port models as can be the G-parameters models. This work particularly focuses on the analysis of different power converters using the well-known dc bus signaling control strategy. Thus the modeling of the diverse possible states in which this control technique can operate, and more important the transitions among them, are investigated. In addition, the feasibility of applying system level control techniques to the polytopic models of the converters, such as current sharing or voltage restoration, is considered.

**11:20AM***Study on DC Arc Faults in Ring-Bus DC Microgrids with Constant Power Loads [#1182]*  
Xiu Yao   
, University at Buffalo, SUNY, United States

DC microgrid offers significant advantages such as control simplicity and less conversion stages for energy storage, renewables and electronic load integration. However, its implementation is highly restricted by the development of dc protection system. Especially, the series dc arc faults have been posing significant challenges due to low fault current level. This paper explores the impact of dc arc fault in dc microgrids with constant power loads (CPLs). An effective power flow and dc arc modeling method is presented, based on which the dc arc fault responses at different locations are analyzed. It is concluded that with a ring bus structure and droop control, the microgrid is naturally resistant to series dc arc fault at the source and dc buses. However, arc fault by the load side can still cause serious damages. Based on the fault responses study, dc arc detection and protection considerations are discussed.

**11:45AM***Stability Analysis and Improvement of a Dual Active Bridge (DAB) Converter Enabled DC Microgrid based on a Reduced-order Low Frequency Model [#457]*  
Qing Ye, Ran Mo and Hui Li   
, Florida State Univeristy, United States

This paper analyzes the harmonic instability due to interactions among power converters and negative incremental impedance of load converters in a dual active bridge (DAB) converter enabled DC microgrid. Based on derived system impedances, it is found that the challenge of a DAB converter enabled microgrid stability is low frequency terminal behaviors of integrated units, which is different from other converters powered DC microgrids. At this frequency range, tightly regulated load converter exhibits constant power load (CPL) behavior even with low control bandwidth, which degrades system stability by aggravating interactions among power converters. In addition, the deployed power management strategy enables mode transition of energy storage units to achieve high reliability, which further complicates system impedance characteristics. To solve these issues, global minor loop gain (GMLG) and unified stability metric (USM) are derived to analyze system stability under different operation mode. A reduced-order low frequency model is developed to provide an insightful view of resonance mechanism. Based on the proposed model, the effect of power converter interactions and constant power load behavior are analyzed coordinately. Finally, an effective impedance shaping technique is proposed to improve system stability by eliminating resonance path in the reduced-order low frequency model. Experimental results and more simulation results will be provided in the final paper.

Datacenters and Telecommunication Applications

Wednesday, September 21, 10:30AM-12:10PM, Room: 102E, Chair: Philip Krein, Johan Enslin

**10:30AM***Soft-Switching Operation of Edge-Resonant Output-Inductor-Less Full-Bridge Converter [#636]*  
Kazuhide Domoto, Yoichi Ishizuka, Seiya Abe and Tamotsu Ninomiya   
, Nagasaki University, Japan; Kyushu Institute of Technology, Japan; Green Electronics Research Institute, Kitakyushu, Japan

Recently, the rapid growth of internet traffic has increased the number of ICT equipment in a data center, and the electric power consumption has also been increased. Therefore, the energy-saving techniques are required in a data center. In order to satisfy the energy-saving and increase the data-center scale, the High-Voltage Direct-Current (HVDC) power distribution system is effective. This system has an advantage of higher efficiency due to the smaller number of conversion stages when compared with the conventional AC system. Furthermore, ICT equipment and its power supply units should be miniaturized so as to install the much large number of equipment in a limited space of the data center. Two concepts of the energy saving and space saving are combined into high power density of the power converter systems. From this background, the circuit topology and implementation technique of a rectifier unit which is a part of power supply unit in the HVDC distribution system have been investigated before. Here, an Output-Inductor-Less (OIL) full-bridge converter has been proposed. This proposed circuit topology suppresses the surge voltage due to the recovery of side diodes, and miniaturizes the converter because the number of circuit components is reduced. On the other hand, some problems occur, such as the increasing switching-loss of primary switches and another high-frequency noise generation. This paper proposes a novel synchronous rectifier driving for the OIL full-bride converter in order to solve these problems, and examines the noise reduction effect, and the relationship between ZVS operation condition and circuit parameters. The proposed method does not need an external component, and then the smaller size is maintained.

**10:55AM***High Efficiency Two-Stage 48V VRM with PCB Winding Matrix Transformer [#940]*  
Mohamed Ahmed, Chao Fei, Fred C. Lee and Qiang Li   
, CPES - Virginia Tech, United States

High efficiency power supply solutions for data centers are gaining more attention, in order to minimize the fast growing power demands of such loads, the 48V Voltage Regulator Module (VRM) for powering CPU is a promising solution replacing the legacy 12V VRM by which the bus distribution loss, cost and size can be dramatically minimized. In this paper, a two-stage 48V-12V-1.8V 250W VRM is proposed, the first stage is a high efficiency, high power density isolated - unregulated DC-DC converter (DCX) based on LLC resonant converter stepping the input voltage from 48V to 12V. The Matrix transformer concept was utilized for designing the high frequency transformer of the first stage, an enhanced termination loop for the synchronous rectifiers and a non-uniform winding structure is proposed resulting in significant increase in both power density and efficiency of the first stage converter. The second stage is a 4-phases buck converter stepping the voltage from 12V to 1.8V to the CPU. Since the CPU runs in the sleep mode most of the time a light load efficiency improvement method by changing the bus voltage from 12V to 6V during light load operation is proposed showing more than 8% light load efficiency enhancement than fixed bus voltage. Experimental results demonstrate the high efficiency of the proposed solution reaching peak of 91% with a significant light load efficiency improvement.

**11:20AM***Hierarchical Protection Architecture for 380V DC Data Center Application [#1475]*  
Kai Tan, Xiaoqing Song, Chang Peng, Pengkun Liu and Alex Huang   
, North Carolina State University, United States; North Carolina State Univeristy, United States

The DC distribution system is becoming an appealing spot due to its higher energy efficiency in recent years. Nowadays, it has been already applied in data centers, commercial buildings, electrical vehicles charger station and DC micro grid systems, etc. However, there are a lot of challenges in DC application which is not critical in traditional AC system, such as arcing, capacitive charging and discharging, etc. All of them make the protection strategy and architecture an important issue for DC application. In this paper, one 3-level hierarchy circuit protection architecture is proposed with developed solid state circuit protection hardware. It is designed with considering the power rating for DC data center load conditions. Analysis and experimental results based on 380V DC voltage have been conducted and discussed.

**11:45AM***Device Loss Comparison of GaN Device Based LLC, Dual Active Bridge and Phase Shift Quasi Switched Capacitor Circuit [#783]*  
Boxue Hu, Xuan Zhang, Lixing Fu, He Li, Yousef M. Abdullah, Yafeng Wang, Lurao Liu and Jin Wang   
, The Ohio State University, United States

Gallium Nitride (GaN) power devices become commercially available in recent years and they have demonstrated great potential in DC power supply applications. In this paper, the device loss of three GaN device based isolated DC/DC circuits, LLC circuit, dual active bridge (DAB) circuit and phase shift quasi switched capacitor (QSC) circuit, is investigated and compared using telecom power supply application as an example. The device loss of the three circuits at various load and operation frequency conditions is calculated and compared for a 1 kW, 400 to 48V application case. The comparison results show that phase shift QSC circuit is a promising circuit candidate for DC power supply applications. A 1 kW, 0.5 MHz, 400-48 V GaN device based phase shift QSC converter prototype is built to verify the analysis results.

Transportation Electrification II

Wednesday, September 21, 10:30AM-12:10PM, Room: 102D, Chair: Sinisa Jurkovic, Bruno Lequesne

**10:30AM***Loss Optimizing Control of a Multiphase Interleaving DC-DC Converter for Use in a Hybrid Electric Vehicle Drivetrain [#1098]*  
Rashidreza Karimi, Dennis Kaczorowski, Alexander Zlotnik and Mertens Axel   
, Leibniz University of Hannover, Germany

In this paper, the application of a multiphase interleaving DC-DC converter in the drivetrain of an electric vehicle is studied. At first, a method for controlling the converter is proposed which ensures its operation under variable switching frequency and changing of the number of active phases. The implemented cascade control is designed with the help of a small signal model of the multiphase converter. The controller also features a nonlinear feedforward compensator to improve the transient performance. In the next step, different loss optimizing strategies are developed and discussed, based on the temperature-dependent loss model of the drivetrain. These strategies are to vary switching frequency, DC-link voltage and the number of active phases as well as a so-called passive mode operation. Finally, the efficiency difference between a conventional drivetrain and the modified one is presented which shows efficiency improvement especially at partial load. A test setup is also constructed for experimental results which will be presented at the end of this paper.

**10:55AM***Traction Inverter Evaluation Method Based on Driving Cycles for Electric and Hybrid Electric Vehicles [#677]*  
Fan Xu and Lihua Chen   
, Ford Motor Company, United States

With the increasing demand for environment-friendly and high fuel economy vehicles, most of the automotive manufacturers are working on the development of their electric and hybrid electric vehicles (EVs/HEVs). The traction inverter plays a significant role in EV/HEV system and converts energy between the battery and the electric motors. One of the key challenges during the traction inverter development is how to evaluate its performance in the lab. This paper proposes a method to evaluate the performance of traction inverter in EVs/HEVs. Comparing with the traditional lab test methods, the proposed method uses the real driving cycles of the vehicle and illustrates the traction inverter performance in real driving conditions. The experimental results show the benefits of the proposed method.

**11:20AM***Model Predictive Control based Field-weakening Strategy for Traction EV used Induction Motor [#153]*  
Jianyong Su, Rui Gao and Iqbal Husain   
, Harbin Institue of Technology, China; North Carolina State University, United States

In typical traction Electric Vehicle applications, the DC-link voltage varies during transient accelerating and decelerating process in field-weakening region. The calculated reference voltages of current PI regulators tend to be larger than the one in steady state, which will result in the undesired flux-producing current oscillations. This further deteriorates the electromagnetic torque performance. To solve this issue, a model predictive control (MPC) based field-weakening algorithm is proposed for traction EV used low-voltage induction motor (IM). n this paper, the DC- link voltage utilization, which is usually set as high as possible to output maximum torque, is decreased temporarily to keep the flux-producing current unchanged during the braking process. The model predictive control is adopted for the voltage loop, in which the steady voltage is calculated with steady flux equation. The influence of overlarge voltage calculated from PI regulator is decreased. The simulation and experimental results provide the evidence of improvements of the proposed field- weakening algorithm.

**11:45AM***Design Optimization and Development of Electric Traction Machines for Cadillac CT6 PHEV [#1278]*  
Sinisa Jurkovic, Khwaja Rahman and Peter Savagian   
, General Motors, United States

The Cadillac CT6 plug-in hybrid electric vehicle (PHEV) power-split transmission architecture utilizes two motors. One is an induction motor type while the other is a permanent magnet AC (PMAC) motor type referred to as motor A and motor B respectively. Bar-wound stator construction is utilized for both motors. Induction motor-A winding is connected in delta and PMAC motor-B winding is connected in wye. Overall, the choice of induction for motor A and permanent magnet for motor B is well supported by the choice of hybrid system architecture and the relative usage profiles of the machines. This selection criteria along with the design optimization of electric motors, their electrical and thermal performances, as well as the noise, vibration, and harshness (NVH) performance are discussed in detail. It is absolutely crucial that high performance electric machines are coupled with high performance control algorithms to enable maximum system efficiency and performance. Specifically, key challenges toward that goal are inverter voltage utilization, for maximum power capability and accurate current control for torque production. We focus on the specific challenges in controlling induction machines where the leading requirement form the machine design side to lower leakage inductance has negative ramification on the controllability of the machine.

PFC Rectifiers

Wednesday, September 21, 10:30AM-12:10PM, Room: 202E, Chair: Ned Mohan, Alessandro Costabeber

**10:30AM***Active Virtual Ground - Bridgeless PFC Topology [#550]*  
Carl Ngai-Man Ho, River Tin-Ho Li and Ken King-Man Siu   
, University of Manitoba, Canada; ABB (China) Ltd., China

The paper presents a new bridgeless Power Factor Correction (PFC) topology, using a recently proposed controllable LCL filter, namely Active Virtual Ground (AVG) to achieve efficient power conversion and high frequency (HF) common mode voltage (CM) reduction. The proposed PFC circuit consists of high frequency semiconductors for shaping inductor current, and low frequency semiconductors to form two different LCL structures for different conditions. This reduces grid differential mode (DM) current ripple or inductance. Besides, the PFC CM voltage, a main problem of bridgeless PFCs, is significantly reduced, since the capacitor in the LCL filter clamps the voltage between the grid and the converter ground. The performance of the proposed PFC is experimentally verified. The results show that the proposed PFC guarantees sinusoidal input current, low high frequency common-mode voltage noise and has a good agreement with the theoretical findings.

**10:55AM***A 500 kHz, 3 kW power factor correction circuit with low loss auxiliary ZVT circuit [#1493]*  
Siddharth Kulasekaran and Raja Ayyanar   
, Arizona State University, United States

The paper presents a low-loss auxiliary circuit in a power factor correction (PFC) circuit to achieve zero voltage transition and hence improving the efficiency and operating frequency. The high dynamic energy generated in the switching node during turn-on is diverted by providing a parallel path through an auxiliary inductor and a transistor placed across the main inductor. The auxiliary devices operate at zero current switching and this addition has no effect on the control of the main PFC circuit. The paper discusses the operating principles, design and merits of the proposed scheme with hardware validation on a 3kW/ 500 kHz PFC prototype.

**11:20AM***A Two-Switch Buck-Boost PFC Rectifier With Automatic AC Power Decoupling Capability [#754]*  
Wenlong Qi, Sinan Li, Siew Chong Tan and Shu Yuen Ron Hui   
, The University of Hong Kong, Hong Kong

In this paper, a single-stage power-factor-correction (PFC) rectifier with active power decoupling function is proposed. The proposed rectifier has a low component count as compared to existing solutions. Only two active switches, one inductor and one small power-buffering capacitor are needed. High power factor, wide output voltage range and active power decoupling can be simultaneously obtained. In addition, the rectifier has an inherent automatic power decoupling capability, and no dedicated active power decoupling control is required. Therefore, the control of the rectifier is simple and easy to implement. A 100 W prototype of the proposed rectifier with 110 Vrms/50 Hz input and a regulated DC output voltage ranging from 30 V to 100 V has been constructed and tested. The results show that with only a 15 uF power-buffering capacitor, a power factor of over 0.98, peak efficiency of 93.9% and output voltage ripple of less than 3% has been achieved.

**11:45AM***High Efficiency Bridgeless Power Factor Correction Buck Converter for High Frequency AC Systems [#1396]*  
Zhe Yang, Sitthisak Kiratipongvoot and Chi Kwan Lee   
, The University of Hong Kong, Hong Kong

This paper presents a bridgeless power factor correction (PFC) buck converter for high frequency AC systems. This PFC converter utilizes series resonant circuit at the AC-side to perform the PFC and buck topology at the DC-side to regulate the output voltage. In order to reduce the number of components and to improve the efficiency of the converter, a bridgeless topology is proposed. A detailed circuit analysis has been done. The AC to DC voltage conversion ratio and boundary of the converter operation are explicitly expressed. Afterwards, experimental results are provided to verify the operation of the topology. The converter prototype operates at 100 kHz with an output power of 10 W. Its efficiency is over 90 %. The total harmonic distortion of the input AC current at full load condition is less than 20 %.

Modeling and Control of Multilevel converters

Wednesday, September 21, 10:30AM-12:10PM, Room: 202B, Chair: Mengqi Wang, Marcello Pucci

**10:30AM***An Improved Proportional Pulse Compensation Strategy for DC Voltage Balance of Cascaded H-Bridge Rectifier [#81]*  
Xiang Li, Jian Wang, Xiaojie You and Kun Wang   
, Beijing Jiaotong University, China

DC voltage balance strategy is an important control part for Cascaded H-Bridge Rectifier. Proportional pulse compensation strategy is a typical voltage balance strategy, which can realize DC voltage balance with good performance under special working condition. However, the balance effect may be influenced by load current, and it is hard for self adoption under different load conditions. This paper proposes a kind of improved voltage balance strategy through modeling analysis on the circuit on the basis of this proportional pulse compensation strategy. The load current is introduced to the regulator, so as to better realize DC voltage balance under different load conditions. Simulation and experimental results verify the proposed improved strategy.

**10:55AM***Cost effective Capacitor Voltage Balancing Control for Five-level Grid-tied Inverters [#38]*  
Mingchen Gu, Li Zhang, Kai Sun, Yan Xing and Peng Xu   
, Nanjing Univ. of Aeronautics and Astronautics, China; Hohai University, China; Tsinghua University, China

The neutral point (NP) potential self-balancing of five-level full bridge inverters with conventional modulation strategy is related to the modulation index. Both the voltages of two split-capacitors should be sampled and controlled, when the inverter operates with the low modulation index. Therefore, an improved modulation strategy is proposed to realize the NP potential self-balancing for five-level full bridge inverters within the whole modulation index range. Only the sum of input split- capacitors voltage needs to be sampled, and the hardware cost is reduced. Experimental results verify the effectiveness of the improved modulation strategy.

**11:20AM***A Single Phase T-type Inverter Operating in Boundary Conduction Mode [#393]*  
Zhen Zhang, Junming Zhang and Xinke Wu   
, Zhejiang university, China; Zhejiang University, China

This paper proposes a single phase T-type inverter operating in boundary conduction mode (BCM). In the past, boundary conduction mode has been widely used to achieve valley voltage switching. In this paper, one switching leg of a full-bridge inverter is replaced by a T-type switching leg to further improve the efficiency. Because the T-type switching leg generates three voltage levels, the voltage stress across switches is halved and the switching frequency decreases compared with the conventional two-level full-bridge inverter operating in BCM. As a result, the switching losses and inductor core losses are largely reduced and the efficiency is improved. The characteristics of the proposed inverter are detailed in this paper. A prototype is built and experimental results validate the superiority of the proposed inverter over the conventional two-level full-bridge inverter.

**11:45AM***Three-Phase Four-Wire AC-DC-AC Multilevel Topologies Obtained from an Interconnection of Three-leg Converters [#1146]*  
Ayslan Caisson Noroes Maia, Cursino Brandao Jacobina, Nayara Brandao de Freitas, Antonio de Paula Dias Queiroz and Edison Roberto Cabral da Silva   
, Federal University of Campina Grande, Brazil

This paper investigates three AC-DC-AC multilevel topologies for three-phase four-wire (3P4W) applications obtained from an interconnection of three-leg voltage source converters (VSCs). The topologies provide bidirectional power flow and can be applied in line voltage regulators, universal active power filters and uninterrupted power supplies (UPS). Operating principles, a pulse-width modulation (PWM) technique and an overall control strategy are developed. The PWM and control strategies are suitable to regulate the DC-link voltage and to optimize the harmonic distortion, reducing switching stress and power losses. Simulation results are used to compare the proposed configuration with a conventional solution in terms of harmonic distortion and semiconductor losses. Experimental results are presented to validate the theoretical considerations and were obtained by using IGBTs with dedicated drives and a digital signal processor (DSP) with appropriated plug-in boards and sensors.

Modeling and Control of Resonant Converters

Wednesday, September 21, 10:30AM-12:10PM, Room: 102C, Chair: Rolando Burgos, Marko Hinkkanen

**10:30AM***Extreme Start-Up Response of LLC Converters Using Average Geometric Control [#1322]*  
Mehdi Mohammadi and Martin Ordonez   
, University of British Columbia, Canada

Resonant power converters have become ubiquitous to efficiently process electrical energy, however, their complicated structure challenges linear controllers in anticipating their large signal performance. Since small- signal modeling techniques do not provide sufficient information regarding the large signal behavior of power converters, nonlinear geometric controllers can be employed to tackle the poor large signal dynamic response. In this paper, a nonlinear controller called the average geometric controller is introduced for the LLC converter with the ability of providing an extreme start-up dynamic response and eliminate overshoot. A novel average large signal model is developed and serves as the foundations to develop the average geometric controller for LLC converters. The average large signal model significantly simplifies the large-signal behavior analysis and results in obtaining the average circular trajectories of the LLC converter. In order to validate the theoretical analysis, experimental and simulation results of a 500W prototype LLC converter employing the average geometric controller are presented. The experimental results show a significant increase in start-up performance while the overshoot is eliminated.

**10:55AM***Optimized Resonant Pulsed Power Supplies with Deadbeat - Repetitive Regulation [#758]*  
Chao Ji, Jon Clare and Pericle Zanchetta   
, University of Nottingham, United Kingdom

This paper presents a novel digital deadbeat + repetitive control (DBRC) strategy for output voltage regulation of pulsed power resonant converters used in high energy physics applications. The proposed converter contains three individual series resonant parallel loaded (SRPL) converter arms, which effectively mitigate the influence of resonant tank unbalances on the converter operation. The deadbeat controller is designed to produce fast dynamics of the voltage pulses during the system transient periods, while the repetitive controller is employed to counteract model uncertainties and component variations and hence to achieve a high performance and fine quality in the steady state.

**11:20AM***Control and Operation of Medium-voltage High-power Bi-directional Resonant DC-DC Converters in Shipboard DC Distribution Systems [#1481]*  
Dong Dong, Luis Garces, Mohammed Agamy, Yan Pan, Xinhui Wu, He Xu, Hongwu She, Xiaohong Li and Jian Dai   
, GE global research, United States; GE Global Research, United States; GE global research, China; GE Global Research, China

Shipboard power system is moving towards more insertion of medium voltage (MV) dc sub-system in the existing MVAC power system. Isolated bidirectional dc-dc converter, analogous to a dc energy router, is one of the key enabling components in such a MVDC system to inter-tie different dc buses with the capability of power flow control as well as fault isolation. Control of such converters in medium voltage and high power scale is always a challenge to ensure fast power flow dynamic response and high efficient operation. In this paper, a variable frequency and phase-shift control solution is presented to regulate the bi-directional power flow in a 1kV to 5kV MW-class LLC resonant converter. The proposed method achieves soft-switching on all power devices across the entire power range as well as seamless power direction change. In addition, a system level control is implemented to fulfill the multifunctional operations in the shipboard applications. Both the hardware-in-loop (HIL) test and the hardware test results are presented.

**11:45AM***Inductance Cancellation in RF Resonant Power Converters [#687]*  
Max Praglin, Luke Raymond and Juan Rivas   
, Stanford University, United States

Parasitic inductance cancellation is employed in order to operate a resonant power inverter at 27.12 MHz using a TO-220 through-hole package. A Cauer-type 1 LC network permits the coupling of inductors to achieve cancellation of multiple parasitic inductances and reduces semiconductor device stress in the same way as the Phi2 inverter topology. The elimination of parasitic inductances allows for system cost reduction, increased power handling, and/or relaxation of PCB layout constraints. The inductance cancellation technique is demonstrated through two prototypes (based upon the same silicon MOSFET die) providing 60 W of RF power to a 50-ohm load from a 48 V DC input: one prototype utilizes a small surface-mount package, and another a larger through-hole TO-220 package. (Without inductance cancellation, the lead inductance of the TO-220 is too large and cannot be used in a 27.12 MHz resonant application.) Inductance cancellation was verified through comparing impedances, operating waveforms, and efficiencies between the prototypes with different MOSFET packages.

Electric Machines for Automotive Applications I

Wednesday, September 21, 10:30AM-12:10PM, Room: 102B, Chair: Thomas Jahns, Sinisa Jurkovic

**10:30AM***Retrospective of Electric Machines for EV and HEV Traction Applications at General Motors [#1387]*  
Khwaja Rahman, Sinisa Jurkovic, Peter Savagian, Nitinkumar Patel and Robert Dawsey   
, General Motors, United States

This paper presents a retrospective of electric motor developments in General Motors (GM) for electric vehicle (EV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and fuel cell electric vehicle (FCEV) production programs. This paper includes i) the progression of electric motor stator and rotor design methodologies that gradually improved motor torque, power, and efficiency performance while mitigating for noise, ii) Heavy rare earth (HRE) mitigation in subsequent design to lower cost and supply uncertainty, iii) Design techniques to lower torque ripple and radial force to mitigate noise and vibration issues. These techniques are elaborated in details with design examples, simulation and test data.

**10:55AM***High-Performance Partitioned-Stator Switched Flux Memory Machines with Hybrid Magnets on External Stator for Automotive Traction Applications [#1032]*  
Hui Yang, Z. Q. Zhu, Heyun Lin, Shuhua Fang and Yunkai Huang   
, Southeast University, China; University of Sheffield, United Kingdom

This paper proposes and investigates a new topology of switched flux memory machine, in which the hybrid magnets and armature windings are separately located on external and inner stators, respectively. Due to the effective online permanent magnet (PM) magnetization, the excitation copper loss can be eliminated. Hence, the high efficiency can be maintained across a wide range of speeds and loads, which is desirable for traction applications. Meanwhile, the partitioned stator (PS) design is beneficial to the alleviation of geometric conflicts between magnetic and electric loadings. In addition, the fact that armature windings are located in the inner stator leads to the increase of effective split ratio similar to an external-rotor machine design. Consequently, the torque capability can be further improved compared to its inner-PM counterpart. The machine topologies having PMs mounted on either external or internal stator are introduced first. The design considerations for the slot/pole combination are investigated. Based on the identical basic specifications, the major electromagnetic characteristics of the optimally designed external-PM machine are investigated in comparison to those of its internal-PM counterpart. The analysis results reveal that the EPM-PS-SFMM can provide wider flux regulation range, higher torque capability as well as lower torque ripple than its IPM counterpart, which confirms the validity for the proposed design.

**11:20AM***Test Results for a High Temperature Non-Permanent Magnet Traction Motor [#1576]*  
Tsarafidy Raminosoa, Ayman El-Refaie, David Torrey, Kevin Grace, Di Pan, Stefan Grubic, Karthik Bodla and Kum-Kang Huh   
, GE Global Research, United States; Faraday and Future, United States

Commercially available hybrid and electric vehicles are generally using rare earth PM motors because of their compactness and very good efficiency. But the supply security and price volatility of rare earth materials are still major concerns for the hybrid and electric vehicle industry. Hence, global efforts are underway in several countries on using reduced or non rare earth materials, developing non PM solutions and taking cost out by trading off between material properties and cost.This paper presents a high temperature DC biased reluctance machine which is structurally similar to a conventional SRM. This non PM machine has a DC field winding and an AC three phase armature winding. The machine is equipped with a high temperature 280C rated insulation system. Test results showing machine performance under continuous operation against the FreedomCar 2020 specifications as well as at high temperature up to 280C are presented. A 43 percent improvement in power density was achieved by going to high temperature.

**11:45AM***Vehicular Suspension and Propulsion Using Double Sided Linear Induction Machines [#971]*  
Tom Cox, Fred Eastham and Matt Dickinson   
, The University of Nottingham, United Kingdom; The University of Bath, United Kingdom; Force Engineering Ltd., United Kingdom

This paper presents a new method of combined electromagnetic levitation and propulsion using a double sided pair of linear induction machines and a simple conductive sheet secondary. If the supply phase angle of one primary is modified with respect to that of the other, a controllable lift force can be developed on the conductive secondary and its load at any velocity or when stationary. Further, a resolution force is developed tending to drive the secondary into the center of the air gap, meaning that the system is inherently self-stabilizing without complex position feedback or control. This effect is studied and predicted using finite element analysis and then measured and confirmed using an experimental rig.

PM Machines II

Wednesday, September 21, 10:30AM-12:10PM, Room: 101A, Chair: Siavash Pakdelian, Nicola Bianchi

**10:30AM***Experimental Verification of Rotor Demagnetization in a Fractional-Slot Concentrated-Winding PM Synchronous Machine under Drive Fault Conditions [#696]*  
Gilsu Choi, Yichao Zhang and Thomas Jahns   
, University of Wisconsin - Madison, United States

This paper presents the results of experimental tests designed to verify analytical predictions of the rotor demagnetization characteristics of a 0.6 kW 9-slot/6-pole fractional-slot concentrated winding (FSCW) interior PM (IPM) synchronous machine. The demagnetization characteristics of the rotor magnets in this commercially-produced FSCW-IPM machine are measured using a test configuration that is designed to conduct multiple demagnetization tests on the same test machine under controlled temperature conditions. In this paper, finite element predictions of the rotor demagnetization characteristics of the experimental machine during 3-phase symmetrical short-circuit (SSC) and single-phase asymmetrical short-circuit (ASC) faults are compared to experimental test measurements of the post-fault currents and the magnet flux density distribution following demagnetization, demonstrating very good agreement of many key features. This paper presents the results of experimental tests designed to verify analytical predictions of the rotor demagnetization characteristics of a 0.6 kW 9-slot/6-pole fractional-slot concentrated winding (FSCW) interior PM (IPM) synchronous machine. The demagnetization characteristics of the rotor magnets in this commercially-produced FSCW-IPM machine are measured using a test configuration that is designed to conduct multiple demagnetization tests on the same test machine under controlled temperature conditions. In this paper, finite element predictions of the rotor demagnetization characteristics of the experimental machine during 3-phase symmetrical short-circuit (SSC) and single-phase asymmetrical short-circuit (ASC) faults are compared to experimental test measurements of the post-fault currents and the magnet flux density distribution following demagnetization, demonstrating very good agreement of many key features.

**10:55AM***Influence of Stator Configuration on High Frequency Signal Injection Based Permanent Magnet Temperature Estimation in PMSMs [#1580]*  
Daniel Fernandez, David Reigosa, Devraj Dutt, Zi-Qiang Zhu and Fernando Briz   
, University of Oviedo, Spain; University of Sheffield, United Kingdom

The performance and life expectance of Permanent Magnet Synchronous Machines (PMSMs) is strongly affected by the PM temperature. An increase of the PM temperature reduces the PM strength and consequently the machine torque production capability. Also there is a risk of irreversible demagnetization if PM temperature is too high. Directly measurement of the PM temperature is not easy, PM temperature estimation methods have therefor been widely investigated during the last decade. PM temperature estimation methods can be divided into thermal models, BEMF methods and methods based on the injection of some type of test signal in the stator terminals of the machine. Thermal models require previous knowledge of the machine geometry, materials and cooling system. BEMF and high frequency signal injection methods do not require previous knowledge of the machine geometry or cooling system. However, BEMF methods require that the machine is rotating. High frequency signal injection methods can be used at any speed, including standstill. However, there is a number of issues that can affect to the accuracy of these methods, including stator and rotor designs, machine assembling tolerances and rotor lamination grain orientation. This paper analyzes the sensitivity of high frequency signal based temperature estimation methods to the stator design.

**11:20AM***Analysis and Design Guidelines to Mitigate Demagnetization Vulnerability in PM Synchronous Machines [#1280]*  
Gilsu Choi and Thomas Jahns   
, University of Wisconsin - Madison, United States

A design approach is presented to mitigate demagnetization vulnerability in permanent magnet synchronous machines (PMSMs) by proper selection and design of stator windings and rotor configurations. First, a comparative analysis of the stator demagnetizing MMFs and leakage inductances for surface PM machines equipped with integral-slot distributed windings (ISDW) and fractional-slot concentrated windings (FSCW) is performed under the constraint of equal magnet flux linkage. Finite element analysis is used to build confidence in the predicted variation of flux density over the magnet surfaces in the two machines. Overall, two convenient metrics are proposed to evaluate the relative amplitude of peak demagnetizing MMF and potential rotor temperature rise due to eddy-current losses. This study shows that the FSCW-PM machine is more vulnerable to rotor demagnetization compared to the ISDW-PM machine because of the higher peak demagnetizing MMF applied by the stator winding currents and rich spatial harmonics that increase rotor losses.

**11:45AM***The Nature of the Torque Ripple in Fractional-slot Synchronous PMAREL Machines [#572]*  
Nicola Bianchi, Alessandro Castagnini, Giulio Secondo and Pietro Savio Termini   
, University of Padova, Italy; ABB, Discrete Automation and Motion Division, Italy

This paper deals with the analysis of average torque and torque ripple in synchronous reluctance machines assisted by Ferrite permanent magnets, for applications requiring high torque at low speed. The machines distinguish themselves by an anisotropic rotor and a high number of poles. As a peculiar feature, the analysed machines are characterized by fractional-slot non-overlapped coil windings. When anisotropic rotors are employed in stators with fractional-slot winding, there is a worsening of the torque quality: the average torque decreases and the torque ripple increases with respect to the distributed winding machines. This paper aim is to analyse the nature of the torque generation in such machines, that is, to investigate the magnetic phenomenon causing the average torque decrease and the torque ripple increase.

Multilevel Motor Drives

Wednesday, September 21, 10:30AM-12:10PM, Room: 101B, Chair: Luca Zarri, Yi Deng

**10:30AM***A Fault-Tolerant T-Type Multilevel Inverter Topology with Soft-Switching Capability Based on Si and SiC Hybrid Phase Legs [#1630]*  
Jiangbiao He, Nathan Weise, Ramin Katebi, Lixiang Wei and Nabeel Demerdash   
, GE Global Research, United States; Marquette University, United States; Rockwell Automation, United States

The performance of a novel three-phase four-leg fault-tolerant T-Type inverter topology is presented in this paper, which significantly improves the fault- tolerant capability of the inverter regarding device switch faults. In this new modular inverter topology, only the redundant leg is composed of SiC power devices and all other phase legs contain Si power devices. The addition of the redundant leg, not only provides fault-tolerant solution to switch faults that could occur in the T-Type inverter, but also can share load current with other phase legs.

**10:55AM***An On-Line Diagnostic Method for Open-Circuit Switch Faults in NPC Multilevel Converters [#1649]*  
Jiangbiao He and Nabeel Demerdash   
, GE Global Research, United States; Marquette University, United States

On-line condition monitoring is of paramount importance for multilevel converters used in safety-critical applications. A novel on-line diagnostic method for detecting open-circuit switch faults in neutral-point-clamped multilevel converters is introduced in this paper. The principle of this method is based on monitoring the abnormal variation of the dc-bus neutral-point current in combination with the existing information on instantaneous switching states and phase currents. Advantages of this method include simpler implementation and faster detection speed compared to other existing diagnostic methods in the literature.

**11:20AM***Analysis of Neutral Point Deviation in 3-level NPC Converter under Unbalanced 3-phase AC Grid [#869]*  
Kyungsub Jung and Yongsug Suh   
, Elec. Eng. Chonbuk Nat'l Univ., Korea (South)

This paper presents a neutral point deviation compensating control algorithm applied to a 3-level NPC converter. The neutral point deviation is analyzed with a focus on the current flowing out of or into the neutral point of the dc- link. Based on the zero sequence components of the reference voltages, this paper analyzes the neutral point deviation and balancing control for 3-level NPC converter. An analytical method is proposed to calculate the injected zero sequence voltage for neutral point balancing based on average neutral current. This paper also proposes a control scheme compensating for the neutral point deviation under generalized unbalanced grid operating conditions. The positive and negative sequence components of the pole voltages and ac input currents are employed to accurately explain the behavior of 3-level NPC converter. Simulation results are shown to verify the validity of the proposed algorithm.

**11:45AM***A Modulation Technique of Neutral Point Clamped Converters with Common-Mode Voltage Reduction and Neutral-Point Potential Balance [#935]*  
Meng-Jiang Tsai, Hsin-Chih Chen, Po-Tai Cheng, Meng-Ru Tsai and Yao-Bang Wang   
, National Tsing Hua University, Taiwan

Common mode voltage output is closely associated with switching states in three-phase three-wire neutral-point clamped inverter. Detailed analysis shows avoiding redundant states can effectively improve the common mode voltage, so this paper proposes a pulse width modulation (PWM) technique with zero redundant states to reduce the common mode voltage output, and evaluate their performance with the conventional PWM scheme. This study also takes the issue of neutral point potential compensation into consideration. Laboratory test results are presented to verify the effectiveness of proposed scheme.

PM and IPM Motor Drives III

Wednesday, September 21, 10:30AM-12:10PM, Room: 101CD, Chair: Takahiro Suzuki, Nicola Bianchi

**10:30AM***Magnet Temperature Effects on the Useful Properties of Variable Flux PM Synchronous Machines and a Mitigating Method for Magnetization Changes [#690]*  
Brent Gagas, Kensuke Sasaki, Apoorva Athavale, Takashi Kato and Robert Lorenz   
, University of Wisconsin-Madison, WEMPEC, United States; Nissan Motor Co., Ltd., Japan

Variable flux permanent magnet synchronous machines (VF-PMSMs) use permanent magnet magnetization as an additional degree-of-freedom to reduce losses based on operating conditions (e.g., at medium to high speeds, losses are reduced by using a lower magnetization). Magnet properties are known to be dependent on temperature; therefore, the magnet temperature effects on magnetization manipulation and maximum torque properties in VF-PMSMs are investigated in this paper with FEA simulations and experiments. Increased magnet temperature changes the available range of attainable magnetization levels and makes demagnetization occur more easily; therefore, a different current angle and magnetization are needed for maximum torque operation. The temperature effects on high speed magnetization manipulation methods (which are needed for driving cycle loss reduction and full power capability) are evaluated with simulation and experiments on a prototype 80 kW traction machine. A closed loop method for magnetization manipulation that mitigates the effect of temperature is proposed.

**10:55AM***Nonintrusive Online Rotor Permanent Magnet Temperature Tracking for Permanent Magnet Synchronous Machine Based on Third Harmonic Voltage [#441]*  
Hanlin Zhan and Z.Q. Zhu   
, The University of Sheffield, United Kingdom

In this paper, a novel nonintrusive online rotor PM temperature tracking method for permanent magnet synchronous machine (PMSM) based on the third harmonic voltage is proposed. The proposed method is not affected by inverter nonlinearities and requires no information of winding resistance, d- and q-axis inductances. It is also robust to the speed variation and introduces no perturbation signals. The third PM flux-linkage is estimated and used as the indicator of the rotor PM temperature. Analytical model for the third harmonic voltage based on the magnetic permeance modulation is proposed to analyze the influence of armature currents. Corresponding third PM flux-linkage amplitude extractor is designed based on this analytical model. Moreover, 2 dimensional finite element analysis is also carried out to verify the effectiveness of the proposed analytical model. Self-commissioning method of the third harmonic flux- linkage tracker is also proposed. Finally, experiments on the 12/slot-10/pole surface mounted permanent magnet synchronous machine verifies the proposed online rotor PM temperature tracking method.

**11:20AM***Permanent Magnet Temperature Estimation in PMSM Using Low Cost Hall Effect Sensors [#183]*  
Daniel Fernandez, Doosoo Hyun, Yonghyun Park, David Reigosa, Sang Bin Lee, Dong Myung Lee and Fernando Briz   
, University of Oviedo, Spain; Dept. of Elec. Eng.,Korea University, Seoul, Korea (South); Dept. of Elec. Eng., Hongik University, Seoul, Korea (South)

Knowledge of the permanent magnet (PM) temperature in PM synchronous machines (PMSMs) is of great importance both for control and monitoring purposes. Increase in PM temperature during motor operation can degrade the magnetic flux strength and consequently the machine torque production capability, also can cause irreversible demagnetization of the PM. Direct measurement of the PM temperature is not viable in practice, due to both cost and reliability issues. Indirect PM temperature estimation methods recently studied can require knowledge of thermal or electrical model parameters or can have undesired effects on motor operation. In this paper, the feasibility of using low cost hall-effect sensors for PM temperature estimation is investigated. Hall sensors are present for detecting the initial position of the rotor in majority of PMSM applications for which incremental encoders are used for control. The proposed method can therefore be implemented with low or no additional cost. Experimental results n two IPMSMs show that the method is capable of providing non- invasive estimation of the PM temperature without a priori motor parameter information for monitoring and protection against excessive increase in temperature.

**11:45AM***Analysis and Suppression of Zero Sequence Circulating Current in Open Winding Permanent Magnet Synchronous Machine Drives with Common DC Bus [#448]*  
Hanlin Zhan, Z.Q. Zhu and Milijana Odavic   
, The University of Sheffield, United Kingdom

In this paper, the zero sequence circulating current in open winding (OW) permanent magnet synchronous machine (OW-PMSM) drives with common DC bus is systematically analysed for the first time. It is revealed that the zero sequence circulating current is affected by zero sequence back electromotive force (EMF), cross coupling voltages in zero sequence, from the machine side, pulse width modulation (PWM) induced zero sequence voltage and inverter nonlinearity, from the inverter side. Particularly, the influences from the cross coupling voltages in zero sequence and parasitic effect of inverter nonlinearity are investigated for the first time in this paper. Then the synthetic model of the equivalent zero sequence circuit is proposed as well. Each cause is studied independently via analytical modelling, finite element analysis and experiments. Meanwhile, to tackle this issue, the relevant suppression strategy using frequency adaptive proportional resonant controller is presented and tested on the 3kW OW-PMSM platform.

Wide Bandgap Applications: SiC

Wednesday, September 21, 10:30AM-12:10PM, Room: 202C, Chair: Ruxi Wang, Jerry Hudgins

**10:30AM***A Compact 100-A, 850-V, Silicon Carbide Solid-State DC Circuit Breaker [#230]*  
Damian Urciuoli, Oladimeji Ibitayo, Gail Koebke, Gregory Ovrebo and Ronald Green   
, U.S. Army Research Laboratory, United States

A 100-A, 850-V, solid-state circuit breaker (SSCB)having silicon carbide transistors and diodes was developed. The SSCB conducts 100 A continuously with air cooling in a 32 square-centimeter footprint. It is normally off and unidirectionally blocking, and has a configurable trip response allowing a range of overcurrent transients to be conducted, while maintaining a fast trip response at its fault-current limit. The SSCB also provides remote trip, status output, and reset functions. The time-versus-current trip response of the SSCB was characterized at 25, 50, and 75 degrees Celsius baseplate temperatures using pulsed currents with ramp rates of over 70 amps per microsecond. Saw-tooth-shaped current pulse widths of less than 5 microseconds, with amplitudes of greater than 200 A, were demonstrated.

**10:55AM***Matrix Converter with Sinusoidal Input-Output Filter and Filter Downsizing Using SiC Devices [#446]*  
Yasunori Furukawa, Takeshi Kinomae, Hidenori Hara, Masato Higuchi, Ryoji Tomonaga, Kohei Shirabe and Tsuneo Kume   
, Yaskawa Electric Corporation, Japan

The matrix converter is an AC-to-AC direct power conversion system that can generate variable voltage variable frequency output. There is a topology of Matrix converter having sinusoidal waveforms using output LC filter. It enabled that to provide lower EMI, lower common-mode current, and lower shaft voltage. However, there are some problems that filter size become bulky because of the restriction of switching speed using conventional power module, Silicon IGBT. Downsizing of input- output filter can be realized by employing SiC power devices since they are associated with low losses and can be operated at high frequency. In this paper, the use of SiC power devices in matrix converters is studied and its effect in reducing the size of the input and output filter is verified. A prototype was built for evaluations and the results are presented.

**11:20AM***H-Bridge Building Block with SiC Power MOSFETs for Pulsed Power Application [#1619]*  
Ruxi Wang, Juan Sabate, Fengfeng Tao, Cong Li, Xiaohu Liu and Fei Xu   
, GE Global Research Center, United States; GE Global Research Center, China

This paper presents a H-bridge building block with 1700V SiC MOSFET for a pulsed power application to achieve both high voltage, high current and high switching frequency capability. Both power module level and system level stray inductance is minimized to better utilize the SiC high switching speed capability. Meanwhile, since the large pulsed energy is required to drive the pulsed load, voltage sensing for active DC link voltage compensation is proposed and designed.

**11:45AM***Three-phase active front-end rectifier efficiency improvement with silicon carbide power semiconductor devices [#983]*  
Mao Saijun, Wu Tao, Lu Xi, Popovic Jelena and Ferreira Jan Abraham   
, GE Global Research, China; TU Delft, Netherlands

This paper investigates SiC power semiconductor devices in a three-phase active front-end Boost PWM rectifier for power conversion efficiency improvement. Different from Si IGBT based Boost PFC rectifier, the SiC MOSFET based Boost PFC rectifier can achieve the synchronous rectification by MOSFET channel reverse conduction for efficiency improvement. The operation principle difference of three-phase active front-end Boost PWM rectifier with SiC MOSFET and Si IGBT is introduced. The switching characterizations of 1.2kV SiC MOSFET are provided. 5kW 380VAC input, 800VDC output three-phase active front-end Boost PWM rectifier prototype is built in lab to evaluate the efficiency advantage with SiC device. All SiC power semiconductor devices based circuit achieves about 1.2 percent more efficient compared with all Si devices, and around 0.5 percent more efficient than Si IGBT and SiC diode hybrid device pair for the three-phase Boost PWM rectifier due to low switching loss of 1.2kV SiC MOSFET and reduced conduction loss from the synchronous rectification operation for 1.2kV SiC MOSFET.

LED Drivers

Wednesday, September 21, 10:30AM-12:10PM, Room: 102A, Chair: Huai Wang, David Perreault

**10:30AM***Precise and Full-Range Dimming Control for An Off-Line Single-Inductor-Multiple-Output LED Driver [#752]*  
Sinan Li, Yue Guo, Ting Leung Albert Lee, Siew Chong Tan and Shu Yuen Ron Hui   
, The University of Hong Kong, Hong Kong

In this paper, PWM dimming is studied for an off-line single-inductor-multiple-output (SIMO) LED driver at the string level (i.e., only one power channel is active) and at the system level (i.e., all power channels are active). The issues of employing PWM dimming over a SIMO LED driver are investigated and the corresponding solutions are proposed. With the proposed dimming technique, a SIMO LED driver can achieve a high dimming precision and a full dimming range for each power channel. The proposed PWM dimming method has been practically verified with a 25 W off-line SIMO LED driver prototype.

**10:55AM***Design and Implementation of a Retrofit LED Lamp for AC Mains and Ballasts [#155]*  
Tsorng-Juu Liang, Huan-Hao Chang, Kai-Hui Chen and Li-An Hsu   
, National Cheng Kung University, Taiwan

In this paper, the design and implementation of a retrofit LED lamp for AC mains and ballasts is proposed. The proposed driver contains a simple technique to deal with the different kinds of sources between high frequency power from electronic ballasts and low frequency power from AC grid and electromagnetic ballasts. With this technology, the fluorescent lamp can be replaced with the proposed LED lamp without exchanging the existed lighting fixtures and the circuitry does not need to be rewired, which will decrease the cost of change the entire system. The operating principles of the proposed LED lamp, the design consideration, and the key parameters will be discussed. Finally, a hardware prototype of a 22W retrofit LED lamp is built to verify the feasibility of the proposed method.

**11:20AM***A Current Compensator for Mitigating the Influence of Long Cable Inductance between the LED Driver and the Light Source [#635]*  
Rui Zhou, Ryan Shun-Cheung Yeung, Henry Shu-Hung Chung, John Yau-Chung Chan and Norman Chung-fai Tse   
, City University of Hong Kong, Hong Kong

It is sometimes unavoidable to use a long cable to connect the light source to the driver when they are placed far apart in large scale LED lighting installation. Since LED driver typically delivers pulse-width-modulated current pulses, the long cable inductance will delay the rate of rise of the current pulses and will also cause negative off-state voltage across the light source, reducing luminous output and vitiating the life expectancy of the light source. This paper will present a current compensator, which can mitigate the distortion of the current pulses caused by the long cable. The concept is based on recycling the energy stored in the cable at the end of a current pulse and then driving the light source synchronously with the driver at the beginning of the next current pulse. A prototype for a 12V, 4.5A LED driver has been built and evaluated. Topological states, operations and experimental results will be given.

**11:45AM***Investigation into the Use of Single Inductor for Driving Multiple Series-Connected LED Channels [#883]*  
Xiaoqing Zhan, Henry Shu-Hung Chung and Ruihong Zhang   
, City University of Hong Kong, Hong Kong; Northwestern Polytechnical University, China

This paper provides an investigation into the use of single inductor for driving N series-connected LED channels. For each LED channel, there is a parallel- connected switch controlling the LED channel current and also charging the inductor. Compared with the conventional structure having (N+1) switches and all LED channels connected in parallel, the proposed structure has the merits of 1) requiring only N switches, 2) being insensitive to the duration of the transition switching from one channel to another, and 3) allowing all channels to be driven concurrently in every switching cycle. Mathematical analysis on the topological operations will be discussed. Experimental results of a two- channel system, demonstrating the concept, are presented.

Wednesday, September 21, 1:30PM-3:10PM

Modeling and Control of Alternative Energy Applications

Wednesday, September 21, 1:30PM-3:10PM, Room: 203C, Chair: Eduard Muljadi, Akshay Kumar Rathore

**1:30PM***Using Markov Switching Model for Solar Irradiance Forecasting in Remote Microgrids [#1096]*  
Ayush Shakya, Semhar Michael, Christopher Saunders, Douglas Armstrong, Prakash Pandey, Santosh Chalise and Reinaldo Tonkoski   
, South Dakota State University, United States

In recent years, there has been rapid growth of Photovoltaic (PV) system integration into diesel-based remote microgrids to reduce the diesel fuel consumption. However, due to low correlation of PV power availability with the load as well as uncertainty and variability of the PV power, the benefits of the integration have not been achieved properly. A large energy reserve is required to compensate the fluctuation and improve reliability, which leads to increased operational cost. Solar irradiance forecasting helps to reduce the reserve requirement and improve the PV energy utilization. In this paper, a novel solar irradiance forecasting using Markov Switching Model is proposed for remote microgrids. This forecasting method uses locally available historical irradiance data of the microgrid location to predict day-ahead irradiance. The case study for validating this method for Brookings, SD resulted in Root Mean Square Error (RMSE) of 99.6 W/m^2 for 2008 and 106.8 W/m^2 for 2011.

**1:55PM***Determining Maximum MPP-Tracking Sampling Frequency for Input-Voltage-Controlled PV-Interfacing Converter [#392]*  
Jyri Kivimaki, Moshe Sitbon, Sergei Kolesnik, Alon Kuperman and Teuvo Suntio   
, Tampere University of Technology, Finland; Ariel University, Israel

A maximum-power-point tracking (MPPT) algorithm is essential in all controllers of solar power electronic converters due to the nonlinear current-voltage characteristics of a photovoltaic generator. One of the most widely utilized algorithms are perturbative MPPT techniques such as perturb and observe and incremental conductance methods due to their simple implementation with relatively good tracking performance. However, in order to optimize the performance of such algorithms, the design parameters - sampling frequency and perturbation step size - need to be designed in respect to interfaced power electronic converter. Recent studies have provided state-of-art MPP-tracking design rules for single and two-stage grid-connected PV systems. Unfortunately, the analysis of those studies does not provide analytical results for PV power transient response under feedback-controlled converters. This paper provides reduced-order transfer functions for the converters equipped with either I-type or PID-type controllers in order to approximate the maximum sampling or perturbation frequency for MPP-tracking algorithms. The analysis reveals the factors affecting the transient behavior similarly as in open-loop converter providing valuable tools for optimizing MPP-tracking perturbation frequency design.

**2:20PM***Real-time Emulation of a Pressure Retarded Osmosis Power Generation System [#703]*  
Sudharshan Kaarthik, Jonathan Maisonneuve and Pragasen Pillay   
, Concordia University, Canada

Power production by conversion of salt gradient energy (osmotic power production) has potential for global commercialization. Research on the net- power output and plant configuration provide viable methods for efficient plant operation. In this paper, a novel equivalent electric-circuit model of the pressure retarded osmosis process (PRO) is described and, is used to develop a power hardware-in-the-loop (PHIL) emulator to represent the osmotic power plant which includes impulse turbine and synchronous generator for supplying power to offgrid or isolated loads. The response of the hydraulic, mechanical and electrical components of the system is observed given changes in the source flow-rate and electrical loading. The proposed PHIL emulator provides insight into the operational dynamics and behavior of the PRO system. The proposed real-time emulator is a powerful tool which can advance research and development of pressure retarded osmotic power generation system. Simulation and experimental results are presented in the paper to validate the operation of the proposed PHIL PRO emulator.

**2:45PM***Efficient FCTV Provision considering DWT and DWPT-based Noise Suppression for Overcoming the Noise-Induced Voltage Loss in PEM Fuel Cell [#1585]*  
Jonghoon Kim, Woonki Na and Yongsug Tak   
, Chosun University, Korea (South); California State University, Fresno, United States; Inha University, Korea (South)

This approach gives insight to the design and implementation of the noise suppression based on the wavelet transform (WT) for efficient FCTV signal provision. The most important thing in this approach is to show the comparative analyses on noise suppression between two transforms, such as the discrete wavelet transform (DWT) and discrete wavelet packet transform (DWPT). With an identical mother wavelet of Daubechies db3, the multi-resolution analysis (MRA) -based decomposition and reconstruction processes for reducing the noise- induced voltage loss are basically done in the DWT and DWPT. The marked difference between two transforms is the MRA-based decomposition/reconstruction ability of high frequency component related to the sensing of noisy. For reference, this approach considered two noise suppression techniques such as hard- and soft-thresholdings and checked signal-to-noise ratio (SNR) values for clear evaluation of all comparative analyses. From these results, it is capable of suggesting three conclusions. First, the performance on noise suppression of the DWPT is superior to that of the DWT. Second, the noise-induced voltage loss is more suppressed at soft-thresholding technique when compared to hard- thresholding technique irrespective of the DWT and DWPT. Last, the optimal decomposition/reconstruction levels that have the maximum SNR values are respectively determined in hard- and soft-thresholding techniques. Our definite suggestions sufficiently enable us to achieve an optimal solution for efficient FCTV provision. This approach has been extensively verified by experimental results of the FCTV using a single cell.

Utility Applications IV

Wednesday, September 21, 1:30PM-3:10PM, Room: 202A, Chair: Fariba Fateh, Yipeng Song

**1:30PM***Field Test Results for a 12.47 kV 3-Phase 1 MVA Power Router [#1351]*  
Rajendra Prasad Kandula, Hao Chen, Anish Prasai, Frank Lambert, Joe Schatz, Thomas Powell, Timothy Heidel, Colin Schauder and Deepak Divan   
, Georgia institute of technology, United States; Varentec, United States; Southerncompany, United States; Georgia Power, United States; Advanced Research Projects Agency-Energy, United States; Booz Allen Hamilton, United States

The increasing load, increasing level of penetration of renewable energy and limited investment in transmission infrastructure have significantly increased the need for a smart, dynamically controllable grid. The authors have previously proposed a power flow control device to maximize asset utilization, improve reliability, and reduce congestion. The proposed power router is realized by augmenting an LTC-like transformer with a fractionally-rated direct AC converter. The paper will discuss the field test results of a 12.47 kV, 1 MVA three-phase power router installed on a 12.47 kV feeder. Description of the test feeder, the power router configuration, protection peripherals and initial test results are presented. The test results verify the power router design to address key design challenges associated with utility-grade equipment that includes requirement for high reliability and availability, long life in excess of 20 years with limited or no maintenance schedule, rugged and often harsh operating environment, high BIL ratings and high fault-handling capabilities

**1:55PM***DC Capacitor Voltage Balancing Control for Delta-Connected Cascaded H-Bridge STATCOM Considering the Unbalanced Grid and Load Conditions [#991]*  
Jae-Jung Jung, Joon-Hee Lee, Seung-Ki Sul, Gum Tae Son and Young-Ho Chung   
, Seoul National University, Korea (South); LS Industrial Systems Co. Ltd, Korea (South)

In this paper, a comprehensive control scheme for a delta-connected cascaded h-bridge (CHB) converter based static synchronous compensator(STATCOM) is presented, especially focusing on improving dynamic performance by novel feedforward control method. The method can conspicuously improve the dynamics of circulating current regulation of delta connected CHB STATCOM especially under grid fault condition as well as load unbalance without excessive DC cell capacitor voltage fluctuation. The full scaled simulation results and the down scaled experimental results verify that stable operation is guaranteed for both emulated grid and load unbalance conditions.

**2:20PM***Advanced Grid Simulator for Multi-Megawatt Power Converter Testing and Certification [#1054]*  
Przemyslaw Koralewicz, Vahan Gevorgian, Pieder Joerg, Wim van der Merwe and Robb Wallen   
, ABB, Poland; NREL, United States; ABB, Switzerland

Grid integration testing of inverter-coupled renewable energy technologies is an essential step in the qualification of renewable energy and energy storage systems to ensure the stability of the power system. New types of devices must be thoroughly tested and validated for compliance with relevant grid codes and interconnection requirements. For this purpose, highly specialized custom-made testing equipment is needed to emulate various types of realistic grid conditions that are required by certification bodies or for research purposes. For testing multi-megawatt converters, a high power grid simulator capable of creating controlled grid conditions and meeting both power quality and dynamic characteristics is needed. This paper describes the new grid simulator concept based on ABB's medium voltage ACS6000 drive technology that utilizes advanced modulation and control techniques to create an unique testing platform for various multi-megawatt power converter systems. Its performance is demonstrated utilizing the test results obtained during commissioning activities at the National Renewable Energy Laboratory in Colorado, USA.

**2:45PM***Experimental Verification of Capacitance Reduction in MMC-Based STATCOM [#1264]*  
Takanori Isobe, Long Zhang, Ryuji Iijima, Hiroshi Tadano, Yasuhiko Kawanami and Katsushi Terazono   
, University of Tsukuba, Japan; Yaskawa Electric Corp., Japan

This paper proposes capacitance reduction in modular multilevel converter (MMC) based static synchronous compensator (STATCOM). The MMC-based STATCOM consists of several series connected single-phase STATCOM; therefore, the required capacitance to achieve a constant dc voltage is comparatively high. The basic concept of the capacitance reduction and control principle have been proposed in single-stage STATCOM. This paper extents them to MMC configuration. A control method including capacitor peak voltage based control and voltage balancing control is proposed. The control was demonstrated in a fabricated small-scale setup of 3-cascaded single-phase STATCOM, and waveforms in stead-state and transient are shown. By applying the proposed control technique, the peak voltage was confirmed to be almost constant while the current set-point is changed in step, and a good voltage balancing in dc-side capacitors of each cell was also confirmed.

Modeling, Analysis, and Control of Grid-Connected Converters III

Wednesday, September 21, 1:30PM-3:10PM, Room: 202D, Chair: Ali Davoudi, Edison da Silva

**1:30PM***A Comparative Study of Methods for Estimating Virtual Flux at the Point of Common Coupling in Grid Connected Voltage Source Converters With LCL Filter [#68]*  
Nurul Fazlin Roslan, Jon Are Suul, Alvaro Luna, Joan Rocabert, Ignacio Candela and Pedro Rodriguez   
, Universitat Politecnica de Catalunya, Terrassa, Spain; SINTEF Energy Research, Trondheim, Norway; Abengoa Research Centre, Seville, Spain

Grid connected Voltage Source Converters (VSCs) with LCL filters usually have voltage measurements at the filter capacitors, while it can be important to control the active or reactive power injection at the grid-side of the LCL filter, for instance at a Point of Common Coupling (PCC). Synchronization to the PCC voltage can be obtained by Virtual Flux (VF) estimation, which can also allow for voltage sensor-less operation of VSCs. This paper is presenting a comparative evaluation of methods for estimating the VF at the PCC, considering a VSC connected to the grid through an LCL filter with a Proportional Resonant (PR) controller as the inner current control loop. The VF estimation is achieved by using frequency adaptive dual SOGI-QSGs (DSOGI-VF). The Frequency Locked Loop (FLL) is used in order to keep the positive and negative sequence (PNS) VF estimation inherently frequency adaptive. Three different methods are considered for obtaining the capacitor current needed for estimating the VF at the grid side of the LCL filter which are based on fully estimation by using the voltage sensor-less method, by estimating the capacitor current from the measured voltage or by using additional capacitor current sensors. The results have been compared and validated by simulation studies.

**1:55PM***A Novel Model Predictive Sliding Mode Control for AC/DC Converters with Output Voltage and Load Resistance Variations [#267]*  
Tingting He, Li Li, Jianguo Zhu and Zheng Linfeng   
, FEIT, University of Technology, Sydney, Australia

This paper presents a novel model predictive sliding mode control (MPSMC) strategy for a three-phase grid connected AC/DC converter. The grid current is predicted for controlling the active and reactive power flows for the next sampling time instead of predicting them directly. This MPSMC scheme employs a sliding mode control (SMC) algorithm to calculate the reference values of active and reactive powers in the cost function. The reaching, existing and tracking conditions are analyzed to ensure that the designed sliding surface and control law are effective to control the system. The simulation results by Matlab/Simulink show that the MPSMC strategy is able to meet the system requirements of active and reactive powers, as well as the DC output voltage. Compared with the results obtained from the conventional model predictive PI control (MPPIC) scheme, the proposed strategy can improve the dynamic performance dramatically in terms of the response speed under system disturbances, such as varying output voltage and load demand.

**2:20PM***A Novel Virtual Synchronous Generator Control Strategy Based on Improved Swing Equation Emulating and Power Decoupling Method [#756]*  
Mingxuan Li, Yue Wang, Ningyi Xu, Yonghui Liu, Wenti Wang, Hao Wang and Wanjun Lei   
, Xi'an Jiaotong University, China

A novel practical virtual synchronous generator control strategy considering the differences between inverters and real synchronous generators is proposed in this paper. The proposed control strategy improves the emulation method of damping power in swing equation, which does not need a PLL and in the meanwhile eliminates the effect on the droop coefficient caused by the traditional constant damping factor. Avoiding a differential term, a virtual synchronous impedance is implemented in synchronous rotating reference frame in order to tackle the issue of power coupling caused by the high line impedance ratio R/X. Furthermore, a novel power decoupling method by introducing current compensation into the current loop is proposed to eliminate the power coupling caused by the large power angle, which can noticeably eliminate the power dynamic oscillation and steady-state error. Finally, both the simulation and experimental results validate the effectiveness of the proposed method.

**2:45PM***Virtual Impedance-Based Active Damping for LCL Resonance in Grid-Connected Voltage Source Inverters with Grid Current Feedback [#757]*  
Teng Liu, Zeng Liu, Jinjun Liu and Zipeng Liu   
, Xi'an Jiaotong University, China

Grid-connected Voltage Source Inverter (VSI) with LCL filters, controlled by proportional-resonant compensator in stationary reference frame, is very popular in utility application for its better power quality feature, while the inherent LCL resonance characteristic limits the control loop bandwidth and threatens the system stability. The active damping is essential to dampen the LCL resonance. This paper investigates the active damping method with only grid current feedback. Compared with the most widely used capacitor current feedback active damping, this novel method avoids the use of extra sensors to detect the capacitor current, which possesses the merits of lower cost and higher reliability. By performing the equivalent control block diagram transformation, it is revealed that a virtual impedance in series or parallel with the grid-side inductor can ideally be implemented with specific active damping controllers, which also comprehensively reflects the physical circuit property of grid current feedback active damping. However, the second-order derivative terms are needed in the ideal forms of the active damping controllers which can hardly be realized in practice. To deal with this issue, a second-order transfer function is proposed to approximate the second- order derivative term in the required frequency range for realizing the similar LCL resonance damping performance. Further, a straightforward design method to determine the parameters of the active damping controller is introduced. Finally, the effectiveness of the proposed control method and relevant design strategies are verified both in time and frequency domain.

WBG in Traction Application

Wednesday, September 21, 1:30PM-3:10PM, Room: 102D, Chair: Burak Ozpineci, Anand Sathyan

**1:30PM***Component Design and Implementation of a 60 kW Full SiC Traction Inverter with Boost Converter [#668]*  
Arvid Merkert, Jan-Kaspar Mueller and Axel Mertens   
, Leibniz Universitaet Hannover, Germany

In electric vehicular (EV) traction drives, Silicon Carbide (SiC) devices promise large savings in volume and weight of the converter system, especially when an inverter is combined with a boost DC/DC converter. Such a system has been designed, implemented and tested as a laboratory prototype. Detailed information on the component design is given and the prototypes characteristics are compared with a conventional Silicon IGBT based industrial system.

**1:55PM***Design Methodology for a Planarized High Power Density EV/HEV Traction Drive using SiC Power Modules [#1654]*  
Dhrubo Rahman, Adam Morgan, Yang Xu, Rui Gao, Wensong Yu, Douglas C. Hopkins and Iqbal Husain   
, North Carolina State University, United States

This paper provides a methodology for overall system level design of a high-power density inverter to be used for EV/HEV traction drive applications. The system design is guided to accommodate off-the-shelf SiC power modules in a planar architecture that ensures proper electrical, thermal, and mechanical performances. Bi- directional interleaved DC-DC boost structure and a three-phase voltage source inverter (VSI) have been utilized with the primary focus on the size, weight and loss reduction of passive components. A stacked layer approach has been used for a unique PCB-based busbar, ultra-low profile gate driver, and controller board. This holistic design approach results in a highly compact traction drive inverter with power density of 12.1 kW/L that has lower volume and weight compared to the commercially available state-of-the-art power converter systems.

**2:20PM***A SiC-Based High-Performance Medium-Voltage Fast Charger for Plug-in Electric Vehicles [#711]*  
Srdjan Srdic, Xinyu Liang, Chi Zhang, Wensong Yu and Srdjan Lukic   
, North Carolina State University, United States

This paper presents an isolated medium-voltage, high-power-quality and high efficiency (over 96%), fast charger for plug-in electric vehicles. The proposed fully modular fast charger uses off-the-shelf Silicon Carbide (SiC) power devices to convert the rectified single-phase 2.4 kV medium-voltage input to variable dc output. The adopted input-series-output-parallel unidirectional topology enables converter scalability in both the input voltage and the output power. Using wide bandgap (WBG) power devices enables 9 times reduction in volume and 6 times reduction in weight, compared to the state-of-the-art fast chargers, while exceeding the efficiency of the state-of-the-art fast chargers by more than 1.5%. Based on the system requirements, the appropriate converter topology was selected, its operation was simulated and validated by experiments on the developed fast charger prototype.

**2:45PM***An Integrated Onboard Charger and Accessory Power Converter for Traction Drive Systems with a Boost Converter [#1551]*  
Gui-Jia Su and Lixin Tang   
, Oak Ridge National Lab, United States

Integrating the functionality of battery charging into the propulsion and accessory power system in a plug-in electric vehicle (PEV) can significantly reduce the component count, and thus the cost, weight, and volume for the onboard charger (OBC). Replacing silicon (Si) based power devices with wide-band-gap (WBG) devices can further increase the power density and efficiency and lower the cost as WBG device technology matures and production volume increases. In this paper an isolated, bidirectional integrated OBC and accessory power converter is presented for PEVs employing a boost converter in the traction drive systems and is based on an active front converter (AFC) and a phase shifted dual-active H-bridge converter (PHDAHBC). The AFC utilizes the traction drive inverter, motor, and boost converter and the PHDAHBC is comprised of the transformer and high voltage converter of the 14 V accessory dc-dc converter and an additional H-bridge converter. Experimental results are included for a 6.9 kW OBC integrated into a 60 kW traction inverter with a boost converter using silicon carbide (SiC) MOSFETs and Schottky Barrier Diodes (SBDs).

Single Phase Rectifiers

Wednesday, September 21, 1:30PM-3:10PM, Room: 202E, Chair: Adam Skorek, Euzeli Santos Jr.

**1:30PM***Current-stress Reduction of the Neutral Inductor in a Rectifier with Two Outputs [#246]*  
Wen-Long Ming and Qing-Chang Zhong   
, The University of Sheffield, United Kingdom; Illinois Institute of Technology, United States

In this paper, a recently-reported single-phase rectifier with two outputs (RECTO) is further improved to reduce the current stress of the neutral inductor in the rectifier. The reduction is achieved by moving the neutral inductor away from the path of the grid current. As a result, the inductor only carries the differential current of the dual loads. Since the maximum value of the differential current is much smaller than that of the grid current, the current stress of the neutral inductor can be significantly reduced, and the size of the inductor becomes much smaller, which helps improve the power density of the RECTO. In theory, the current stress can be reduced by at least three times and the inductor size by at least nine times. It is worth noting that the current stress of the switches and the other features of the RECTO, e.g., operation principles, independent DC outputs and unity power factor, are not affected. Comparative experimental results are presented to demonstrate the reduction.

**1:55PM***Single-stage AC/DC Dual Inductor BCM Current-Fed Push-Pull for HB-LED lighting applications [#447]*  
Ignacio Castro, Kevin Martin, Manuel Arias, Diego G. Lamar, Marta M. Hernando and Javier Sebastian   
, University of Oviedo, Spain

A single-stage, AC/DC driver for High Brightness Light-Emitting Diodes (HB-LED) with galvanic isolation is presented in this paper. The driver is based on a Dual Inductor Current-fed Push-Pull (DICPP) converter with each inductor operating in Boundary Conduction Mode (BCM). The interleaving between the two inductors makes possible for the converter to reduce the high input current ripple of a BCM. Moreover, it is fully compliant with IEC 1000-3-2 Class C, and it is also able to achieve high Power Factor (PF). Moreover, the low component count, simplicity and overall outstanding characteristics make this topology suitable for medium power range HB-LED drivers in low cost applications. Finally, the proposed topology has been tested on a 90W prototype for the full range of the US single-phase line voltage, feeding several strings of HB-LED, with an output voltage of 48V at full load. The prototype achieves a maximum efficiency of 92% with 0.99 power factor, 8% THD at full load and guarantees good quality light.

**2:20PM***Asymmetric Single-Phase Current Source Rectifiers [#1535]*  
Louelson Costa, Montie Vitorino, Mauricio Correa, Darlan Fernandes and Oliveira Marcus   
, Federal University of Campina Grande, Brazil; Federal University of Paraiba, Brazil; Tocantins Federal Institute of Technology, Brazil

In this work it is presented a family of six single-phase Current Source Rectifiers (CSR) topologies with asymmetric structures. The topologies present reduced number of active switches and high power factor with low harmonic distortion. Three of the shown structures represent a simplification of full-bridge CSR, replacing two switches from the original topology by two diodes. The other three structures are composed by only one switch, based on single-switch CSR and buck-type CSRs. Details of control strategy and modulation are presented. Experimental results are provided for the full-bridge derived topologies, while simulation results are presented for the other topologies to validate the effective operation of the structures.

**2:45PM***A Bridgeless Controlled Rectifier for Single Split-Phase Systems [#1001]*  
Nustenil S de M. L. Marinus, Cursino B Jacobina, Euzeli C dos Santos Jr., Nady Rocha and Nayara B. Freitas   
, Federal University of Campina Grande, Brazil; Indiana University Purdue University Indianapo, United States

An unidirectional single-phase three-wire rectifier is proposed in this paper. Such a proposed topology is composed of a non-controlled leg, two controlled legs and a capacitor bank. A suitable model and control strategy of the system, including a synchronization method, are proposed as well. The synchronization method, associated with the PWM strategy, imposes the grid currents to have the same phase angle of the generated voltages by rectifier. This method ensures sinusoidal grid currents and mitigate the zero-crossover distortions normally caused by the use of diodes. A comprehensive comparison with two conventional configurations is also presented in this paper. Simulation and experimental results are also presented for validation purposes.

Multilevel Converters

Wednesday, September 21, 1:30PM-3:10PM, Room: 202B, Chair: NingYi Dai, Marcello Pucci

**1:30PM***Modulation Method for Single-Phase Six-Switch Five-Level ANPC Inverter [#141]*  
Lei Kou, Hongliang Wang, Yan-fei Liu, Paresh C. Sen and Yan Zhang   
, Queen's University, Canada

The Five-Level Active-Neutral-Point-Clamped (5L-ANPC) inverter is one of the most popular topologies among five-level inverters since it combines the features of Flying-Capacitor (FC) type and Neutral-Point-Clamped (NPC) type inverters and was commercially used for industrial applications. This paper proposes a novel modulation strategy for a Six-Switch 5L-ANPC (6S-5L-ANPC) topology to keep voltages of DC-link capacitors and FC balanced. The equations to calculate the FC capacitance in active and reactive power conditions are also provided. Simulation and experiment have been carried out to demonstrate the effectiveness of the proposed modulation technique.

**1:55PM***Modified SVPWM to Eliminate Common-Mode Voltages for Five-Level ANPC Inverters [#461]*  
Quoc Anh Le and Dong-Choon Lee   
, Yeungnam University, Korea, Republic of

In this paper, a novel common-mode voltage (CMV) elimination scheme is proposed for five-level active neutral-point clamped (5L-ANPC) inverters, which is based on the space vector PWM (SVPWM). The proposed SVPWM scheme utilizes only 19 voltage vectors producing a zero value of CMV among the whole 125 voltage vectors of the 5L-ANPC inverter. This scheme is also able to control all capacitor voltages by selecting redundant switching states of the inverter appropriately. Therefore, the inverter can be supplied by a single DC source such as a simple diode rectifier. The validity of the proposed SVPWM scheme is verified by simulation results.

**2:20PM***THD and Efficiency improvement in Multi-Level Inverters through an Open End Winding Configuration [#966]*  
Salvatore De Caro, Salvatore Foti, Tommaso Scimone, Antonio Testa, Mario Cacciato, Giuseppe Scarcella and Giacomo Scelba   
, University of Messina, Italy; university of Catania, Italy; University of Catania, Italy

A new approach, based on a current controlled Asymmetrical Hybrid Multilevel Inverter (AHMLI), is proposed to reduce power losses and output current distortion on Multi-Level Inverters (MLI) used in AC motor drives, STATCOM devices, Photovoltaic and Wind generators. A key feature of the proposed approach is that the AC machine (motor or transformer) is operated in an open- end winding configuration, being supplied on one end by a main Multi-Level Inverter and, on the other side, by an auxiliary Two-Level Inverter (TLI). The MLI controls the main active power stream; it operates at a low switching frequency and can be equipped with very low on-state voltage drop IGBT devices. The auxiliary TLI is instead operated according to a conventional high frequency two-level PWM technique and acts as an active power filter providing only a null-average power to the AC machine. As the DC bus voltage of the TLI is remarkably lower that that of the main MLI, the auxiliary inverter can be equipped with low switching losses IGBTs, or even Power MOS devices. Simulations and experimental results confirm that using the proposed approach, the phase current harmonic content is remarkably reduced, the efficiency is increased and in motor drive applications, the torque ripple is mitigated.

**2:45PM***A Source-Type Harmonic Energy Unbalance Suppression Method Based on Carrier Frequency Optimization for Cascaded Multilevel APF [#292]*  
Zezhou Yang, Shangshen Li, Xiaoming Zha, Jianjun Sun and Wang Yi   
, School of Electrical Engineering, Wuhan Universi, China

Cascaded H-bridge multilevel converter based active power filter can compensate high-order harmonics (17th-50th) in middle-high voltage system with relatively lower switching frequency, but at the same time, a special DC capacitor energy unbalance problem is caused. When the compensation current frequency is close to the witching frequency of the H-bridge cell, harmonic power coupling will lead to the divergence of DC voltages, which is called source-type harmonic energy unbalance in this paper. A carrier frequency optimization method is proposed to suppress the unbalance. This method decouples the harmonic voltage with the output current and minimizes the DC voltage ripple only by appropriately adjusting the carrier frequency. The method is verified by the presented simulation results.

DC-DC Converters II

Wednesday, September 21, 1:30PM-3:10PM, Room: 102C, Chair: Yan-Fei Liu, Lixiang Wei

**1:30PM***Small-Signal Model and Control of the Interleaved Two-Phase Coupled-Inductor Boost Converter [#483]*  
Brendan C. Barry, John G. Hayes, Marek S. Rylko, Robert Stala, Adam Penczek, Andrzej Mondzik and Robert T. Ryan   
, University College Cork, Ireland; dtw Sp. z o.o., Poland

Coupled-inductor boost converters are under development for high-current, high-power applications ranging from automotive fuel cells to photovoltaics. This paper presents the small-signal analysis of a coupled-inductor boost converter operating in both CCM and DCM. Due to the complexity of operation of a coupled-inductor boost converter operating in DCM, several small-signal models must be derived. Controllers for the converter are developed using the resulting small-signal models. Experimental validation of these controllers is presented from a 1 kW coupled-inductor boost converter laboratory prototype.

**1:55PM***A Robust Design Framework for Stable Digital Peak Current-Mode Control Under Uniform Sampling [#930]*  
Amit Singha, Santanu Kapat and Jayanta Pal   
, Indian Institute of Technology Kharagpur, India; Indian Institute of Technology Bhubaneswar, India

Fully digital current-mode control (DCMC) has become popular in high frequency applications, primarily because of using the uniform sampling rate for both the voltage and current loops. This requires a lower sampling analog-to-digital converter (ADC), in which the inductor current is sampled once in every switching cycle and the ripple current is emulated in the digital domain. Thus, this remains an important concern about the selection of the emulated current slope. Earlier approaches attempt to extract the actual slopes of the inductor current either using model predictive algorithms or using online computation by considering a few extra current samples. These methods are highly sensitive to system parameters and increase computational complexity. Moreover, this paper reports that even if accurate slope information is available, the uniform voltage-loop sampling often leads to sub-harmonic instability, even with the duty ratio less than 0.5. Using discrete-time models, design methods show that the required stabilizing slope is different from the actual current slope, and the slope magnitude needs to be increased for a higher controller gain. This provides a robust design framework to devise a stable DCMC technique for fast recovery, without attempting to find the actual slope information. A buck converter prototype is made and the proposed controller is implemented using an FPGA device.

**2:20PM***Modeling and Decoupled Control of a Non-isolated High Step-up/down Bidirectional DC-DC Converter [#434]*  
Haixu Shi, Xi Xiao, Hongfei Wu and Kai Sun   
, Tsinghua University, China; Nanjing University of Aeronautics Astronautics, China

Bidirectional DC-DC converters play a very important role in energy storage systems. High voltage conversion ratio, high efficiency and economy are challenging issues for the research and development of advanced bidirectional DC-DC converters. In this paper, the modeling and control of a new non-isolated high step-up/down bidirectional DC-DC converter is studied. This converter is a combination of buck-boost and dual-active-half-bridge converter. It features wide-range high voltage conversion ratio and high efficiency due to full soft switching. However, the circuit coupling causes troubles in control stability. For instance, in island boost mode, oscillation easily occurs if output voltage of high-pressure is still directly regulated by shifted phase. Hence A dynamically accurate enough model is required for analysis and more stable control method is needed. For the modeling, scholars have made some research on calculating power delivered by the transformer with its series inductor current, but they have not taken the series inductor current as a state variable in full frequency domain. Such methods achieve good outcomes in steady-state, but are at a cost of dynamic inaccuracy more or less. In this paper, an average modeling technique which considers transformer series inductor current as a state variable in full frequency domain for dynamic accuracy is proposed. A decoupled control is also proposed to achieve a leap in stability. Simulation and experiment results are also presented to verify the proposed average model and the decoupled control.

**2:45PM***Non-Isolated High-Gain Three-Port Converter for Hybrid Storage Systems [#1140]*  
Jorge Garcia, Ramy Georgious, Pablo Garcia and Angel Navarro-Rodriguez   
, University of Oviedo, Spain

This work proposes a non-isolated power electronic topology to interface two distinct electrical energy storage units to a DC link, resulting in a Hybrid Storage System. The proposed solution, called Series-Parallel Connection, allows for interfacing these three ports in a simple, compact and reliable approach, based on the standard configuration of the H-bridge converter. The main advantage is that one of the storage units can be of much smaller voltage ratings than the other two, avoiding the use of multilevel or galvanic-isolated power stages. The resulting structure is compared against the most significant transformerless alternatives based on the H-bridge converter, stating their advantages and drawbacks. An analysis of the switching and conduction losses in the power switches of the proposed solution is carried out in order to state the design constraints at which this solution presents improved efficiency versus the alternatives. A final set of experiments in a 10 kW built prototype demonstrates the feasibility and states the benefits as well as the main limitations of the proposed scheme.

Reliability, Diagnostic and Faults Analysis in Power Converters I

Wednesday, September 21, 1:30PM-3:10PM, Room: 102E, Chair: Jiangchao Qin, Martin Ordonez

**1:30PM***System-level Reliability Assessment of Power Stage in Fuel Cell Application [#1510]*  
Dao Zhou, Huai Wang, Frede Blaabjerg, Soeren Kundsen Kaer and Daniel Blom Hansen   
, Aalborg University, Denmark; Dantherm Power A/S, Denmark

High efficient and less pollutant fuel cell stacks are emerging and strong candidates of the power solution used for mobile base stations. In the application of the backup power, the availability and reliability hold the highest priority. This paper considers the reliability metrics from the component-level to the system-level for the power stage used in a fuel cell application. It starts with an estimation of the annual accumulated damage for the key power electronic components according to the real mission profile of the fuel cell system. Then, considering the parameter variations in both the lifetime model and the stress levels, the Weibull distribution of the power semiconductors lifetime can be obtained by using Monte Carlo analysis. Afterwards, the reliability block diagram can further be adopted to evaluate the reliability of the power stage based on the estimated power semiconductor reliability. In a case study of a 5 kW fuel cell power stage, the parameter variations of the lifetime model prove that the exponential factor of the junction temperature fluctuation is the most sensitive parameter. Besides, if a 5-out-of-6 redundancy is used, it is concluded both the B10 and the B1 system- level lifetime can be remarkably increased compared to when no redundancy is used.

**1:55PM***A Novel Online ESR and C Identification Method for Output Capacitor of Flyback Converter [#168]*  
Hui Li, Kai Yao, Xufeng Zhou, Fei Yang and Junfang Zhang   
, Nanjing university of science and technology, China; Nanjing University of Science and Technology, China

As electrolytic capacitor is apt to fail in power system, it is very important to monitor its ESR and C. A novel online monitoring method of capacitor's ESR and C for DCM Flyback converter is propose in this paper. Based on the ac component of capacitor voltage, the calculation model is founded. The method needs no current sensor and is effective for the converter operating at any switching frequency and duty cycle. This simulation results validate the effectiveness of the method.

**2:20PM***Fault Ride-Through Capability for Grid-Supporting Inverters [#1023]*  
Prasanna Piya, Masoud Karimi-Ghartemani and Ali S. Khajehoddin   
, Mississippi State University, United States; University of Alberta, Canada

Voltage control strategy has been observed as being more advantageous than current control strategy for microgrid applications where grid-connected and standalone operation of grid-supporting inverters are desired. Voltage control, however, limits the ability to directly control the inverter current. As a result, the fault ride-through or the low-voltage ride-through (LVRT) capability becomes more challenging to address. This paper develops a method for addressing this challenge by adding an auxiliary controller to the main voltage control system to enable the inverter to ride through the grid faults and inject a balanced current with controlled real and reactive components. Moreover, soft transition into the fault and out from the fault is achieved by the proposed controller. Derivations, partial stability analysis and detailed simulation results are presented.

**2:45PM***Analysis of Hybrid Energy Storage Systems with DC Link Fault Ride-Through Capability [#1145]*  
Ramy Georgious, Mark Sumner, Jorge Garcia and Pablo Garcia   
, University of Oviedo, Spain; University of Nottingham, England

In this work, a Fault Ride-Through control scheme for a non-isolated power topology for Hybrid Energy Storage Systems in a DC microgrid is presented. The Hybrid System is created from a Lithium-Ion Battery and a Supercapacitor Module coordinated to achieve a high-energy and high-power storage system; it is connected to a DC link to interface to the outer system. The power topology under consideration is based on the buck-boost bidirectional converter, and it is controlled through a bespoke modulation scheme in order to obtain low losses in nominal operation. The operation of the proposed control during a DC link short-circuit failure is shown as well as a modification to the standard control in order to achieve Fault Ride-Through once the fault is over. The operation of the converter is theoretically developed and it is verified through simulation and experimental validation.

Electric Machines for Automotive Applications II

Wednesday, September 21, 1:30PM-3:10PM, Room: 102B, Chair: Heath Hofmann, Jing Xue

**1:30PM***Optimisation of the Torque Quality of a Combined Phase Transverse Flux Machine for Traction Applications [#398]*  
Jamie Washington, Cristofaro Pompermaier and Glynn Atkinson   
, Hoganas Great Britian Ltd., United Kingdom; Hoganas AB, Sweden; Newcastle University, United Kingdom

Transverse flux machines can be a torque dense solution for applications requiring a relatively low speed such as electrically assisted bicycles or scooters. Common drawbacks include a high torque ripple caused by a high cogging torque and high back electromotive force harmonics. Cogging torque is of particular importance as it can be felt even when the system is disengaged and the bicycle is being pushed. This paper uses an optimisation procedure to reduce the cogging torque and overall torque ripple of a recently introduced type of transverse flux machine. This machine topology has been shown to have a 10% increase in torque compared to more conventional TFM designs but at the cost of an increased cogging torque and therefore torque ripple. During the optimisation there is a trade-off between reductions in cogging torque and the overall torque production of the machine, this will be analysed and compared to a more conventional TFM design to ensure the benefits of the newer design continue.

**1:55PM***An Examination for Improvement of Constant Output Characteristics at High-Speed Region in a Spoke-Type IPMSM using Ferrite Permanent Magnet by Changing the Shape of Rotor Surface [#1496]*  
Shoya Nagano, Masatsugu Takemoto and Satoshi Ogasawara   
, Hokkaido University, Japan

In recent years, interior permanent magnet synchronous motors (IPMSMs) using ferrite permanent magnet are being studied for high power density motor application, such as electric vehicles. However, the residual flux density of ferrite magnet is lower than that of rare-earth permanent magnet. Thus, in general, it is difficult for IPMSMs using ferrite magnet to maintain constant high output power in high-speed region. Accordingly, a spoke-type IPMSM using ferrite magnet with specification similar to the currently commercially available IPMSM using rare-earth magnet is examined in this research. Owing to increasing constant output power in high-speed region, analysis with 3D-FEA was conducted and the analysis results show that the constant output characteristics in high-speed region are improved by contriving the shape of the rotor surface. Moreover, experimental results of a prototype of the examined spoke-type IPMSM using ferrite magnet will be presented in this paper.

**2:20PM***Variable Flux Permanent Magnet Synchronous Machine (VF-PMSM) Design to Meet Electric Vehicle Traction Requirements with Reduced Losses [#710]*  
Apoorva Athavale, Kensuke Sasaki, Brent Gagas, Takashi Kato and Robert Lorenz   
, University of Wisconsin-Madison, WEMPEC, United States; Nissan Motor Co., Ltd, Japan

Variable flux permanent magnet synchronous machines (VF-PMSMs) in which the magnetization state (MS) of low coercive force (low-Hc) permanent magnets can be actively controlled to reduce losses in applications that require wide-speed operation have been proposed recently. While prior focus has been on achieving MS manipulation without over-sizing the inverter and obtaining higher torque capability, this paper extends the design objectives to include the power requirements of an electric vehicle traction motor over its entire speed range. Finite element methods are used to study the effect of combinations of low-Hc and high-Hc permanent magnets arranged in either series or parallel on the performance of VF-PMSMs. It is shown that while both configurations help improve the torque density, only the series configuration can help improve the high speed power capability. Experimental results showing the variable MS property, torque-speed capability and loss reduction capability of a series magnet configuration VF-PMSM test machine are presented.

**2:45PM***Comparison of Traction Motors that Reduce or Eliminate Rare-Earth Materials [#1668]*  
Ayman El-Refaie, Tsarafidy Raminosoa, Patel Reddy, Steven Galioto, Di Pan, Kevin Grace, James Alexander and Kum-Kang Huh   
, GE Global Research, United States; GE Global research, United States

Important global efforts are underway toward lowering the cost of electric machines for electric and hybrid vehicles by reducing or eliminating the use of rare earth materials which have been experiencing significant price increases and volatility. This paper will present several designs that reduce or eliminate rare-earth materials. All these designs are targeting the same set of specifications of 55kW peak at 2800 rpm and 30kW continuous over a speed range going from 2800 rpm to 14000 rpm. This provides a fair basis of comparison of various machine topologies. The paper will provide a quantitative comparison of the performance of various machine topologies as well as highlight the key tradeoffs.

PM Machines III

Wednesday, September 21, 1:30PM-3:10PM, Room: 101A, Chair: Hamid A. Toliyat, Jie Shen

**1:30PM***Active Voltage Regulation of Partitioned Stator Switched Flux Permanent Magnet Generator Supplying Isolated Passive Load [#444]*  
Hanlin Zhan, Z.Q. Zhu and Zhongze Wu   
, The University of Sheffield, United Kingdom

In this paper, an active voltage regulation strategy of the partitioned stator switched flux permanent magnet (PM) (PS-SFPM) generator is proposed to enable the PS- SFPM generator supplying isolated passive load to obtain a stable output voltage at different load conditions. The target is achieved through mechanically varying the relative inner stator position and adjusting the PM flux-linkage. Over the designed working range, zero output voltage regulation ratio can be obtained when compared to the non-adjusted one. The proposed method provides a solution for generator system supplying isolated passive loads to overcome the uncontrolled characteristics of the passive components. Both the field-circuit coupled finite element analysis and experiment results verify the effectiveness of the proposed method.

**1:55PM***Coupled and Simplified Model of the Symmetrical and Asymmetrical Triple Star Nine-Phase Interior Permanant Magnet Machines [#1051]*  
Olorunfemi Ojo   
, Tennessee Tech University, United States

In this paper triple-star nine phase symmetrical and asymmetrical wound IPM machines are modeled by means of a full order coupled modeling approach. A simplified model which predicts the average fundamental behavior is also proposed. Comparative computer simulations of these two models are provided with experimental results.

**2:20PM***Design and Analysis of a Novel Three-phase Flux Reversal Machine [#268]*  
Yuting Gao, Ronghai Qu, Dawei Li, Jian Li and Yongsheng Huo   
, Huazhong University of Science and Technology, China

In this paper, a novel flux reversal machine (FRM) is proposed to achieve a larger torque density and a smoother torque waveform than the conventional FRM. The proposed FRM have the same combinations of stator and rotor slots, winding pole pair and PM usage, but different PM arrangement with the conventional FRM, i.e. in the conventional FRM, a pair of PMs is mounted on the surface of each stator teeth, while the PMs of the proposed FRM are uniformly attached to the entire inner surface of the stator. First, the origination from the conventional FRM to the proposed FRM is introduced. Then, the effects of the rotor slot number, split ratio, stator/rotor slot opening ratio, PM thickness and pole arc on average torque and cogging torque are investigated and analyzed, which give a reasonable prediction for maximum achievable power density and minimum possible cogging torque of the proposed FRM. Moreover, the proposed FRM is compared to a conventional FRM in terms of back-EMF, cogging torque, rated torque, torque ripple and overload capabilities. Finally, a 12-stator-slot/17-rotor-slot FRM prototype is built to verify the theoretical analyses.

**2:45PM***Design, Control and Implementation of a Non-Rare-Earth Flux Switching Permanent Magnet Machine [#1635]*  
Chandan Sikder, Iqbal Husain and Wen Ouyang   
, NC State University, United States; ABB US Corporate Research Center, United States

This paper presents the control and performance of the Flux-Switching Permanent Magnet (FSPM) machine designed and built with non-rare-earth magnets. The design objective has been minimization of volume and cost, and reduction of cogging torque, noise and vibrations. A comprehensive methodology has been adopted for the design of a 12/10 segmented stator structure FSPM. Machine parameters have been identified with a nonlinear model taking mutual coupling and saturation into account. Stator flux oriented vector controller has been implemented using the machine parameters. Experimental results for the designed and fabricated are included for performance validation.

Drive Applications

Wednesday, September 21, 1:30PM-3:10PM, Room: 101B, Chair: Davide Barater, Uday Deshpande

**1:30PM***A New Normal Mode dv/dt Filter With Resistor Failure Detection Circuit [#56]*  
Mark Baumgardner and Mahesh Swamy   
, Yaskawa America, Inc., United States

Insulated Gate Bipolar Transistors (IGBTs) will soon be replaced by wide band gap devices (SiC and GaN) as the choice for power semi-conductor switch in Voltage Source Inverters. These devices have extremely fast rise time and fall time compared to IGBT devices. The high dv/dt of PWM outputs create excessive voltage stress in the insulation system of AC motors due to voltage reflection issues associated with motors at large distances from the drive. In many oil field applications, the distance between the motor and the Variable Frequency Drive (VFD) approaches 300m. In walking rig applications, it is common to use multiple smaller sized conductors per phase, bunched together, to achieve the desired ampacity. This practice results in higher than usual value of the cable parasitic capacitance. Traditional dv/dt filters used for mitigating over-voltage at motor terminals, have been found to be inadequate in reducing the over voltage at the motor terminals in such oil field installations. The damping resistor often experiences high voltage and gets damaged. A new dv/dt filter suitable for use with high power AC motors at distances nearing 300m with a built-in resistor failure detection circuit is proposed here. Test results are given to demonstrate its efficacy.

**1:55PM***Simulation of Cable Charging Current and Its Effects on Operation of Low Power AC Drives [#510]*  
Helen Lewis-Rzeszutek, Ripunjoy Phukan, Rangarajan Tallam, Mark Solveson and Timothy Clancy   
, Rockwell Automation, United States; Georgia Institute of Technology, United States; Ansys, United States; General Cable, United States

In Variable Frequency Drive (VFD) systems, long motor leads can have many detrimental effects, including cable charging current, overvoltage at the motor terminals, and voltage stress on power modules. Different types of AC system grounding can also interact with long motor leads to yield undesirable effects on drive operation. Analyzing models of various components of a drive system is useful to determine any potential issues prior to installation and to recommend any needed filter solutions to mitigate these issues. However, prior cable models have several shortcomings and are inadequate for fully understanding long cable effects prior to VFD system installation. In this paper, a commercially available finite element analysis (FEA) tool is applied to generate a wide frequency range model for a multi-conductor VFD cable. It is shown that this cable model can be used in a system level simulation to determine application issues for low power AC drives. The method is validated using experimental tests on selected cable, motor and drive combinations.

**2:20PM***Systematic Modeling for a Three Phase Inverter with Motor and Long Cable using Optimization Method [#1645]*  
Hui Zhao, Shuo Wang, Jianjun Min and Zhi Yongjian   
, University of Florida, United States; China South Railway, China

A systematic behavior model based on time domain simulation to predict the EMI performance of a motor drive system is analyzed. Optimization algorithm is used to improve the accuracy of modeling of the impedances of the conduction path.

**2:45PM***Performance Evaluation of SiC MOSFETs with Long Power Cable and Induction Motor [#1587]*  
Peizhong Yi, Puneeth Kumar Srikanta Murthy and Lixiang Wei   
, Rockwell Automation, United States

Silicon Carbide (SiC) MOSFETs, as wide-bandgap semiconductor device, has capability to switch at much higher frequency in comparison with their silicon (Si) counterparts. Industrial motor drive is usually connected to induction motor with long shielded cable. This long shielded cable introduces parasitics such as stray inductance and capacitance to the system, which affects SiC MOSFETs performance for inverter side and reflected wave transient overvoltage on motor terminals. In this paper, switching performance of SiC MOSFETs is systematically studied under different length of cables with both inductor load and induction motor load. Compared with standard DPT, turn on and turn off current ringing decays slower with longer cable which leads to 20% higher switching loss. Long cable also contributes to longer turn off time at low current. Furthermore, a theoretical reflected wave model with SiC MOSFETs based inverter is presented to estimate motor terminal voltage. A much higher dv/dt caused by SiC MOSFETs fast switching results in more strict requirements for both motor and cable selection. The test shows motor transient voltage achieved twice DC bus voltage with 100ft cable under single pulse condition. If pulse width modulation (PWM) is not adjusted properly, motor voltage may shoot up to 3-4 times DC bus voltage. The potential solutions for switching performance improvement and reflected wave are also discussed and provided in this paper.

Sensorless Drives I

Wednesday, September 21, 1:30PM-3:10PM, Room: 101CD, Chair: Giacomo Scelba, Ramakrishnan Raja

**1:30PM***Design consideration of interior permanent magnet machine position sensorless drive using square-wave voltage injection [#285]*  
Shih-Chin Yang, Sheng-Ming Yang and Jing-Hui Hu   
, National Taiwan University, Taiwan; National Taipei University of Technology, Taiwan

Although it is widely known that the saliency-based position sensorless drive is able to achieve the closed-loop control at zero and low speed, there is little literature addressing the consideration on the selection of injection voltage frequency. This paper evaluates the square-wave injection voltage at different frequencies for the design of interior permanent magnet (PM) machine saliency-based sensorless drive. It is shown that more flux saturation on high frequency (HF) d-axis inductance occurs than the saturation on q-axis inductance due to the magnetic relaxation. The performance of saliency-based sensorless drive can be enhanced by properly designing the frequency of injection voltage. An IPM machine with a saliency ratio (Lq/Ld) of 1.41 is tested for the experimental evaluation.

**1:55PM***A Synchro-Perspective-Based High-Frequency Signal Injection Method for Position-Sensorless Vector Control of Doubly-Fed Induction Machines [#654]*  
Anuwat Srivorakul and Surapong Suwankawin   
, Chulalongkorn University, Thailand

In this paper, a novel high-frequency (HF) injection method of sensorless drive for doubly-fed induction machines (DFIM) is proposed. The high-frequency voltage is injected into the rotor winding and according to the concept of synchro, the rotor position can be simply extracted from the phase difference among the stator current and the rotor current regardless of machine and grid parameters. In addition, the proposed scheme is robust against the disturbance of high-frequency stator voltage propagated from the grid. The vector phase- locked loop (PLL) technique is employed to calculate rotor position and rotor speed simultaneously and the global stability of the PLL is validated. The feasibility of the proposed concept is verified by the experimental results with 4-kW DFIM drive.

**2:20PM***Enhancing Estimation Accuracy by Applying Cross-Correlation Image Tracking to Self-Sensing Including Evaluation on a Low Saliency Ratio Machine [#1100]*  
Timothy Slininger, Yinghan Xu and Robert Lorenz   
, University of Wisconsin, Madison, United States

Image tracking self-sensing, which utilizes cross-correlation to detect the rotor position by evaluating the orientation of the current image across a full injection cycle can enhance estimated accuracy and improve tolerance to noise. Cross-correlation over a full injection cycle replaces the classical heterodyning demodulation used in traditional point-tracking methods and is known to produce significant harmonic content. Image tracking mitigates dynamic degradation since there is no longer a need for low pass filtering of the harmonic content. Cross-correlation also handles complex images well. This paper will document how by the careful consideration of the machine properties at an operating point, details of the current response can be used to generate a complex image over the full injection cycle. This paper will also show how cross-correlation of the sampled image over each full injection cycle with this detailed model, allows for a more accurate estimate of position when compared to traditional point-tracking methods. These methods are evaluated experimentally on a low saliency ratio SPM and compared to classical rotating and pulsating point-tracking HFI methods.

**2:45PM***The Crowded Axis of the Frequency: Optimal Pole/Zero Allocation for a Full Speed Sensorless Synchronous Motor Drives [#637]*  
Virginia Manzolini, Mattia Morandin and Silverio Bolognani   
, University of Padova, Italy

Full speed sensorless Interior Permanent Magnet Synchronous Motor (IPM-SM) drives estimate the rotor speed and position by means of a HF voltage injection at standstill or low speed operation and by some form of back-electromotive force or PM flux estimator at the medium and high speed range. Both the estimation strategies include an inner loop closed by a PI+I regulator for extracting speed and position, as well as high-pass, low-pass filters devoted to the separation of the injected HF voltages from the fundamental power voltages. Gains and time constant of the regulator, together with filter bandwidths interfere with PWM and injected frequency as well as with current control and speed control bandwidths. In order to design a high performance drive, all these frequencies have to be appropriately allocated. The paper gives a deep theoretical insight of the subject, supported by simulations and experimental validations, aimed to propose a complete set of guidelines for the optimal design of the sensorless control of IPM-SM drives.

Junction Temperature Sensing and Monitoring

Wednesday, September 21, 1:30PM-3:10PM, Room: 102A, Chair: Adam Skorek, Tanya Gachovska

**1:30PM***An IGBT Junction Temperature Measurement Method via Combined TSEPs For Eliminating Impact of Collector Current [#202]*  
Xiang Wang, Chong Zhu, Haoze Luo, Zhou Lu, Wuhua Li, Xiangning He, Jun Ma, Guodong Chen, Ye Tian and Enxing Yang   
, Zhejiang University, China; Aalborg University, China; Shanghai Electric, China

Junction temperature of insulated gate bipolar transistors (IGBTs) plays an important role in power semiconductor devices reliability. However, it is difficult to have direct access to the chip to obtain the junction temperature. This paper provides a new approach to extract the junction temperature by using combined thermo-sensitive electric parameters (TSEPs) during turn-off transient due to the parasitic inductor LeE. The turn-off delay time (tdoff) and voltage peak of LeE during turn of transient (VeEPeak) can both serve as TSEP for their temperature dependence. High linearity is inherited when the two TSEPs are combined to extract the junction temperature. The proposed method has the clear advantages of simple realization compared with individual TSEP to obtain junction temperature because it eliminates the influence of collector current (IC). Experiments have been implemented to evaluate the effectiveness of the proposed solution.

**1:55PM***DeltaTj Control of Switching Power Devices at Thermal Boundaries via Physics-Based Loss Manipulation [#857]*  
Timothy Polom, Boru Wang and Robert Lorenz   
, University of Wisconsin-Madison, United States

To optimize the lifetime of switching power semiconductors, this paper presents improvements in the performance and coordination of a control system to regulate power device junction temperature, Tj, and its change during power cycles, DeltaTj. This research proposes a DeltaTj control law which closes a control loop on the sample average rate of change state, Tj- dot-bar, and subsequently introduces active thermal capacitance and conductance to the closed-loop thermal system dynamics. Also proposed in this paper is a supervisory state machine which ensures thermal control interrupts nominal system-level control only when temperature bounds are exceeded, and coordinates smooth transitions as Tj(k) or DeltaTj(k) approach their respective boundaries. Experimental evaluation of the proposed control methods illustrates well damped Tj(k) and DeltaTj(k) responses and gradual adjustment of the manipulated inputs switching frequency and duty ratio. The paper also provides models to decouple the cross-coupling of manipulated inputs, allowing independent manipulation of conduction and switching losses.

**2:20PM***Online Junction Temperature Monitoring Using Turn-Off Delay Time for Silicon Carbide Power Devices [#1279]*  
Zheyu Zhang, Xuanlyu Wu, Fred Wang, Daniel Costinett, Leon Tolbert and Blalock Benjamin   
, the University of Tennessee, United States; Xi'an Jiaotong University, China

Junction temperature is a critical indicator for health condition monitoring of power devices. Concerning the reliability of emerging silicon carbide (SiC) power semiconductors due to immaturity of new material and packaging, junction temperature measurement becomes more significant and challenging, since SiC devices have low on-state resistance, fast switching speed, and high susceptibility to noise and parasitics in circuit implementations. This paper aims at developing a practical and cost-effective approach for online junction temperature monitoring of SiC devices using turn-off delay time as the thermo-sensitive electrical parameter (TSEP). The sensitivity is analyzed for fast switching SiC devices. A gate impedance regulation assist circuit is designed to improve the sensitivity by a factor of 60 and approach hundreds of ps per Celsius in the case study with little penalty of the power conversion performance. Also, an online monitoring system based on three gate assist circuits is developed to monitor the turn-off delay time in real time with the resolution within hundreds of ps. In the end, the micro-controller is capable of reading junction temperature during the converter operation with less than 0.5 Celsius measurement error. Two testing platforms for calibration and online junction temperature monitoring are constructed, and experimental results demonstrate the feasibility and accuracy of the proposed approach. Furthermore, the proposed gate assist circuits for sensitivity improvement and high resolution turn-off delay time measurement are transistor based and suitable for chip level integration.

**2:45PM***Simple Analog Detection of Turn-off Delay Time for IGBT Junction Temperature Estimation [#676]*  
Simon Weber, Michael Schlueter, Daniel Borowski and Axel Mertens   
, Leibniz University of Hanover, Germany

IGBT modules suffer from ageing due to thermal and power cycling. Bond wire lift-off or solder layer degradation are the known failure mechanisms. For condition monitoring, an estimation of the junction temperature during operation is necessary. For this purpose, an analog measurement board consisting of simple components is presented. The turn-off delay time is evaluated for temperature estimation. Moreover, a validation of the temperature estimation with an infrared camera is performed.

Wide Bandgap Applications: GaN

Wednesday, September 21, 1:30PM-3:10PM, Room: 202C, Chair: Filippo Chimento, Jean-Luc Schanen

**1:30PM***Design of a 10 kW GaN-based High Power Density Three Phase Inverter [#1059]*  
He Li, Xuan Zhang, Zhengda Zhang, Chengcheng Yao, Feng Qi, Boxue Hu, Liming Liu and Jin Wang   
, The Ohio State University, United States; ABB Corporate Research, United States

The medium power rating two-level three phase voltage source inverter is among the most popular power conversion systems. The typical switching frequency of the commercial medium power rating inverter, however, is limited to tens of kHz. By increasing the switching frequency and using emerging gallium-nitride devices, the size of the overall system can be greatly reduced. This paper begins by reviewing all commercially available GaN power transistors and their package technologies. The GS66516T device from GaN Systems is selected due to its suitable ratings and superior package performance. Then, a half-bridge structure is designed for this device to achieve low parasitic inductance and strong cooling capability at the same time. The dynamic characterization results of this 650V/60A Enhancement-mode GaN transistor are extracted with the proposed half-bridge structure. A gate drive circuit with comprehensive protection function is integrated. Based on the proposed phase-leg structure, a 10 kW three phase inverter prototype is built and the experimental waveform is shown at the end.

**1:55PM***High-frequency DC-DC Converter in Electric Vehicle Based on GaN Transistors [#1348]*  
Zhenjin Pang, Xiaoyong Ren, Junlin Xiang, Qianhong Chen, Xinbo Ruan and Wu Chen   
, Nanjing Univ. of Aeronautics and Astronautics, China; Southeast University, China

DC-DC converter in electric vehicle (EV) has higher demand for high efficiency and power density. Faster switching is beneficial to high power density. Gallium nitride (GaN) power transistors have the advantages of faster switching capability, smaller parasitic parameters and better electric parameters, which make them more suitable to achieve higher switching frequency and power density in DC-DC converter in EV. In this paper, the two-staged converter consisting of Buck and multi-phase interleaved half- bridge LLC series resonant converter (LLC-SRC) is chosen as the main topology. The current sharing problem caused by the mismatch between resonant components is analyzed and improved. Design consideration of driver of low-voltage GaN transistor and the efficiency improvement of high-voltage GaN transistor in LLC-SRC are analyzed. A 1MHz/2kW, 330V/12V DC-DC converter prototype is fabricated and efficiency comparison experiment with Si MOSFET is finished. Experimental results show that GaN power transistor has superior high frequency switching capability and efficiency advantage compared to Si MOSFET.

**2:20PM***A GaN-based Flying-Capacitor Multilevel Boost Converter for High Step-up Conversion [#1420]*  
Zitao Liao, Yutian Lei and Robert Pilawa-Podgurski   
, University of Illinois, United States

Compact high step-up DC/DC conversion to provide high DC voltage has numerous applications. A conventional boost converter has many limitations with regard to achieving high voltage gain with high power density and efficiency. The flying-capacitor multilevel (FCML) converter topology has many inherent advantages to overcome many of the limitations of the conventional boost converter. In this work, a GaN-based 7-level flying capacitor multilevel boost converter prototype has been implemented and achieved 100 V to 914 V conversion at 750 W output power with 92.7% peak efficiency, and 200 V to 966 V conversion at 900 W output power with 93.7% peak efficiency within the tested load range.

**2:45PM***A GaN based High Frequency Active-clamp Buck Converter for Automotive Applications [#1114]*  
Chenhao Nan, Raja Ayyanar and Youhao Xi   
, Arizona State University, United States; Texas Instruments Inc., United States

Automotive point-of-load (POL) dc-dc converters have wide input voltage range and strict EMI limitation requirements. In order to avoid the AM band interference, the switching frequency is desired to be above 2 MHz. The buck converter is widely used for this application but it has low efficiency at high switching frequency and poor EMI performance due to high dv/dt slew rate. A new active-clamp buck converter is employed in this paper, which features soft-switching for all switches, and thereby high efficiency and low EMI emission. The converter analysis, design considerations are presented. The converter is implemented with GaN FETs, due to its lower Figure-of-Merit (FOM), to further improve the efficiency. The implementation issues with GaN FETs are addressed. Then the experimental results with a 2.2 MHz prototype demonstrate superior performance of this converter.

Applications of Droop Control

Wednesday, September 21, 1:30PM-3:10PM, Room: 203AB, Chair: Tsorng-Juu Liang, Keyue Smedley

**1:30PM***Energy Storage Size and Fuel Consumption Reduction in a Microgrid Using Virtual Droop Control Framework [#1110]*  
Ashish Solanki and Adel Nasiri   
, SandC Electric, United States; UW-Milwaukee, United States

Microgrid can provide higher reliability, resiliency, sustainability, energy security and surety. Even though there are greater benefits, maintaining stability of microgrid is a major challenge especially with high penetration of renewables into microgrid. The existing approaches to address the problem of stability is to add large energy storage and increase generation capacity. In this paper, energy storage reduction and fuel minimization in a microgrid using Virtual Droop Control (VDC) has been proposed to deal with the problem of stability. The size selection of energy storage system for microgrid to ensure proper operation during microgrid transition has been discussed in this paper. The simulation results has been presented for 24 hours load, wind and solar PV radiation profile for the studied Fort Sill microgrid system using VDC controls. The energy profile for energy storage systems and natural gas generators and fuel consumption of natural gas generators have been presented for standard droop control method and compared with VDC controls.

**1:55PM***Seamless Black Start and Reconnection of LCL-filtered Solid State Transformer Based On Droop Control [#1397]*  
Yonghwan Cho, Yongsu Han, Richard Byron Beddingfield, Jung-Ik Ha and Subhashish Bhattacharya   
, North Carolina State University, United States; Seoul National University, Korea (South)

The solid state transformer (SST) is an emerging technology that can replace conventional passive transformers and actively manage renewable energy resources, energy storage devices, and loads. In this paper, a seamless black start control strategy is proposed for an SST-based smart grid system that has fault ride-through capability when it is islanded from the grid. Also, a method is developed to achieve smooth reconnection to the grid after a fault is cleared. The main component of the proposed control strategy is control of the high-voltage side converter of the SST (HV SST), which is based on a combination of droop control and an LCL filter. A single-loop controller for the capacitor voltage of the LCL filter is proposed, and simple criteria for setting compensator gains are provided. A low-voltage scaled SST system is introduced, and the controllers of the converters within the system are described. The proposed control strategy has been tested in simulation and experimentally on a low-voltage scaled testbed.

**2:20PM***A Circulating Current Suppression Method for Parallel Connected Voltage-Source-Inverters (VSI) with Common DC and AC Buses [#197]*  
Baoze Wei, Xiaoqiang Guo, Josep M. Guerrero and Juan C. Vasquez   
, Aalborg University, Denmark; Yanshan University, China

This paper describes a theoretical with experiment study on a control strategy for the parallel operation of three-phase voltage source inverters (VSI), to be applied to uninterruptible power systems (UPS). A circulating current suppression strategy for parallel VSIs is proposed in this paper based on circulating current control loops used to modify the reference currents by compensating the error currents among parallel inverters. Both of the cross and zero-sequence circulating currents are considered. The proposed method is coordinated together with droop and virtual impedance control. In this paper, droop control is used to generate the reference voltage of each inverter, and the virtual impedance is used to fix the output impedance of the inverters. In addition, a secondary control is used in order to recover the voltage deviation caused by the virtual impedance. And the auxiliary current control loop is added to acquire a better average current sharing performance among parallel VSIs, which can effectively suppress both of the cross and zero-sequence circulating currents. Experimental results are presented in order to verify the effectiveness of the proposed control strategy.

**2:45PM***Decentralized Method for Load Sharing and Power Management in a Hybrid Single/Three-Phase Islanded Microgrid Consisting of Hybrid Source PV/Battery Units [#1053]*  
Yaser Karimi, Josep M. Guerrero and Hashem Oraee   
, Sharif University of Technology, Iran; Aalborg University, Denmark

This paper proposes a new decentralized power management and load sharing method for a photovoltaic based, hybrid single/three-phase islanded microgrid consisting of various PV units, battery units and hybrid PV/battery units. The proposed method takes into account the available PV power and battery conditions of the units to share the load among them and power flow among different phases is performed automatically through three-phase units. Modified active power- frequency droop functions are used according to operating states of each unit and the frequency level is used as trigger for switching between the states. Efficacy of the proposed method in different load, PV generation and battery conditions is validated experimentally in a microgrid lab prototype consisted of one three- phase unit and two single-phase units.

DC Microgrids III

Wednesday, September 21, 1:30PM-3:10PM, Room: 203DE, Chair: Giovanna Oriti, Tsorng-Juu Liang

**1:30PM***A New Secondary Control Approach for Voltage Regulation in DC Microgrids [#790]*  
Saeed Peyghami-Akhuleh, Hossein Mokhtari, Pooya Davari, Poh Chiang Loh and Frede Blaabjerg   
, Sharif University of Technology, Iran; Aalborg University, Denmark

In this paper the effect of secondary controller on voltage regulation in dc Micro-Grids (MGs) is studied. Basically, centralized or decentralized secondary controller has been employed to regulate the voltage drop raised by the primary controller. However, in the case of high capacity MGs and long feeders with much voltage drop on the line resistances, the conventional methods may not guarantee the voltage regulation on the load busses. Therefore, in addition to compensate the voltage drop of the primary controller, it is necessary to regulate the voltage of critical loads. In this paper, a new voltage regulation strategy is proposed to regulate the voltage of MG by employing the average voltage of identified busses, which are determined by the proposed modal analysis. Numerical steady state analysis and preliminary simulation results validate effectiveness of the proposed scheme. Furthermore, experimental results with a scaled down laboratory prototype are performed to demonstrate the viability of the proposed approach.

**1:55PM***CERTS Microgrids with Photovoltaic Microsources and Feeder Flow Control [#1478]*  
Zhe Chen, Dinesh Pattabiraman, Robert H. Lasseter and Thomas M. Jahns   
, University of Wisconsin Madison, United States

A promising approach is proposed for extending the appealing features of the CERTS microgrid concept beyond its robust plug-and-play and autonomous control characteristics to include the integration of photovoltaic (PV) microsources with reduced volatility at the grid interface. The steady-state and transient characteristics of a proposed CERTS PV microgrid that incorporates a droop-controlled PV inverter source and a feeder flow-controlled microsource are explored under a variety of demanding conditions including time-variant changes in irradiance, microgrid islanding, and load change events. The proposed configuration exhibits well-behaved transient responses for a variety of events, as well as the ability to maximize the harvest of PV energy during all modes of operation. Simulations and experimental results from a CERTS microgrid testbed are provided to validate the proposed approach.

**2:20PM***Combined Optimization of SSCB Snubber and Freewheeling Path for Surgeless and Quick Bus Fault Interruption In Low-Voltage DC Microgrid [#365]*  
Wenjun Liu, Xiaoqi Xiong, Hua Yang, Kun Feng, Si Zhang and Fei Liu   
, Wuhan University, China

When a bus fault occurs in a low-voltage DC microgrid, solid-state circuit breakers (SSCB) on either end of the DC bus assume the responsibility of the isolation of the faulted section, while the freewheeling path attached between SSCB and the bus takes on the task of fault energy absorption and fault current damping. However, during fault interruption, the snubber attached in parallel with SSCB for overvoltage suppression will influence the fault energy absorption performance of freewheeling path, while the resistance of the freewheeling path will also influence the overvoltage suppression capability of the SSCB snubber. Hence, this paper analyzed the interaction between the two and proposed a combined design so as to optimize the fault interruption performance for minimum SSCB overvoltage, and shortest fault clearing time, with less cost and size. Preliminary experiments are conducted on a 400V/DC prototype, and the experimental results demonstrated the effectiveness of the design.

**2:45PM***Symmetric Droop Control for Improved Hybrid AC/DC Microgrid Transient Performance [#588]*  
Philip Hart, Robert Lasseter and Thomas Jahns   
, University of Wisconsin-Madison, United States

A droop-controlled, hybrid ac/dc microgrid represents a robust architecture that can coordinate the operation of multiple distributed sources while minimizing the power conversion stages. While the reduced-order nonlinear dynamics of grid-forming, droop-controlled inverter-based microgrids have been rigorously shown to be stable for a wide range of operating parameters, the problem of analyzing the transient stability characteristics of droop- controlled hybrid ac/dc architectures has not been adequately addressed. This work reviews the link between the Virtual Synchronous Machine control concept and grid-forming droop control, and introduces a new droop control strategy for ac/dc hybrid microgrids, termed Symmetric Droop Control (SDC). SDC better addresses the dynamic interactions between the ac and dc sub-grids of the hybrid microgrid, by ensuring that the interfacing inverter appropriately represents the dc sub-grid dynamics when interacting with other inverters. SDC can help to ensure that the reduced-order, nonlinear dynamics in both the ac and dc networks remain predictable and well-behaved during large disturbances in the ac network.

Wednesday, September 21, 3:30PM-5:10PM

Wind Energy Control and Operations

Wednesday, September 21, 3:30PM-5:10PM, Room: 203AB, Chair: Eduard Muljadi, Pedro Rodriguez

**3:30PM***Small Scale Reluctance Synchronous Generator Wind-Turbine System with DC Transmission Linked Inverters [#85]*  
Joshua Cole Mitchell, Maarten Jan Kamper and Christoph M. Hackl   
, Stellenbosch University, South Africa; Munich University, Germany

In this paper, an alternative layout for small scale back-to-back variable speed wind turbine systems is proposed. This novel layout is created by splitting the converters at their common DC bus and linking them through the wind turbine tower with a DC rated cable. The grid-tie voltage source converter (VSC) is placed at ground level and the generator VSC is placed in the nacelle. Not only does the DC transmission cable allow electrical power to be transferred with minimal copper losses, it allows the nacelle to be more compact and maintenance friendly. The control of a reluctance synchronous generator (RSG), variable speed, fixed pitch wind turbine and grid-connected system is detailed in this paper with specific attention to the control of the DC bus voltage with a DC-link cable. DC bus voltage dynamics are investigated with practical measurements on a 3 kW wind turbine emulator, RSG and LCL-filter grid-tie system. Power input steps at rated power are used to perturb the DC bus system for two different cable lengths. Two minutes of emulated wind speed using a 150 m cable length is also tested. The results show that the DC-link dynamics are controllable.

**3:55PM***Short-Term Forecasting of Inertial Response from a Wind Power Plant [#149]*  
Eduard Muljadi, Vahan Gevorgian and Anderson Hoke   
, National Renewable Energy Laboratory, United States

The total inertia stored in all rotating masses (synchronous generators, induction motors, etc.) connected to a power system grid is an essential force that keeps the system stable after disturbances. Power systems have been experiencing reduced inertia during the past few decades. This trend will continue as the level of renewable generation (e.g., wind and solar) increases. Wind power plants (WPPs) and other renewable power plants with power electronic interfaces are capable of delivering frequency response (both droop and/or inertial response) by a control action; thus, the reduction in available online inertia can be compensated by designing the plant control to include frequency response. The source of energy to be delivered as inertial response is determined by the type of generation (wind, photovoltaic, concentrating solar power, etc.) and the control strategy chosen. The importance of providing ancillary services to ensure frequency control within a power system is evidenced from many recent publications with different perspectives (manufacturer, system operator, regulator, etc.) This paper is intended to provide operators with a method for the real-time assessment of the available inertia of a WPP. This is critical to managing power system stability and the reserve margin. In many states, modern WPPs are required to provide ancillary services (e.g., frequency regulation via governor response and inertial response) to the grid. This paper describes the method of estimating the available inertia and the profile of the forecasted response from a WPP.

**4:20PM***A 3.0MW Case Study of the Influence of PM Cost on Wind Turbine Cost of Energy [#1183]*  
Matthew Henriksen, Bogi Bech Jensen, Nenad Mijatovic and Holboell Joachim   
, ABB Corporate Research, United States; University of the Faroe Islands, Faroe Islands; Technical University of Denmark, Denmark

A wind turbine generator optimization procedure based on minimization of annual energy losses and drivetrain cost is presented. Pareto fronts for four different 3.0MW wind turbine drivetrains utilizing permanent magnet synchronous machines are presented. The results are given for three different scenarios in which the magnet cost is varied. This variation affects direct- drive machines the most. A number of trends in the direct-drive generator optimization variables are presented as well.

**4:45PM***Direct Power Control of a Doubly Fed Induction Generator Wind Power System in Stand-Alone and Grid-Connected Modes with Seamless Transition [#1195]*  
Sam Mahmodicherati, Malik Elbuluk and Yilmaz Sozer   
, The Universityof Akron, United States; The University of Akron, United States

This paper describes a direct power control (DPC) strategy used for a doubly fed induction generator (DFIG) for wind energy system. The system operates in stand-alone (SA) and can connect to the grid through smooth transition. The proposed control structure is capable of regulating the stator voltage and frequency for an isolated load in case of grid outage. Also, when grid is available, it can control the stator voltage phase to be synchronized with grid voltage and connect with seamless transition to the grid. The basic structure of DPC method consists of hysteresis-based controller (HBC) and switching table that are used in both SA and grid-connected (GC) modes. The proposed control strategy is analyzed, simulated using MATLAB/Simulink and PSIM, and also validated experimentally using a 7.5 hp DFIG laboratory set up.

Energy Harvesting Systems

Wednesday, September 21, 3:30PM-5:10PM, Room: 203C, Chair: Paul Barendse, Xiongfei Wang

**3:30PM***Temperature Dependence of Efficiency in Renewable Magnetohydrodynamic Power Generation Systems [#615]*  
Eva Cosoroaba and Babak Fahimi   
, The University of Texas at Dallas, United States

Magnetohydrodynamic (MHD) power generation is based on Faraday's law: a magnetic field induces electron movement into a passing, conductive fluid. If captured, these electrons are the source of magnetohydrodynamically generated power. Combustion gas and liquid metal (LM) have been used as work fluid in the research of the '60s, but to gain renewable energy source properties, liquid gallium is used in a circular channel to allow the use of lower temperature thermal energy as the main input. This paper focuses on the detailed description of the proposed renewable system, the efficiency derivation as well as the study of the efficiency sensitivity considering loading conditions, generator dimension, and metal temperature. Conclusions and outlook on specific applications of LM-MHD are given.

**3:55PM***Modeling, Analysis and Design of An Undersea Storage System [#997]*  
Seyyedmahdi Jafarishiadeh, Mehdi Farasat and Amir Masoud Bozorgi   
, Louisiana Sate University, United States; Louisiana State University, United States

This paper presents the modeling, performance analysis, and design of an undersea storage system (USS). The USS can be employed for conditioning the output power of wave energy converters (WECs) and floating wind turbines (FWTs) at sea or ocean cites. A mathematical model is developed to describe the governing equations of the USS operation. Next, based on the developed model, a storage system is designed for a 3 MW direct drive WEC. Finally, some guidelines and discussions on determining the USS energy capacity, power capacity, optimum size, and installation depth are presented.

**4:20PM***The Joint Design of a Compressed Air and Wind Energy System for Mechanical Spillage Recovery [#1186]*  
Jie Cheng and Fred Choobineh   
, University of Nebraska-Lincoln, United States

A novel configuration of a compressed air assisted wind energy conversion system is proposed to capture the mechanical spillage of a wind turbine and store it as the compressed air. The compressed air storage could be used to supplement electric power generation. The compact design utilizes the surplus capacities of blades and generator, and combines the compressor and expander into one machine. The compressed air subsystem serves as a buffer between the blade power and the electric output power. It mitigates the power discrepancy between them and gives another degree of freedom for energy management. The performance simulation shows that the joint design of compressed air and wind turbine system helps to increase the power generation by 12%. The discounted energy cost during one week is decreased by 15%, compared to a traditional wind turbine. The sensitivity analysis is conducted to evaluate the feasibility of the proposed system in variable conditions.

**4:45PM***Experimental Control of a Hydraulic Wind Power Transfer System under Wind and Load Disturbances [#1615]*  
Masoud Vaezi and Afshin Izadian   
, Purdue School of Engineering and Technology, United States

Hydraulic wind power transfer systems deliver the captured energy by the blades to the generators through an intermediate medium i.e. hydraulic fluid. This paper develops a control system for an experimental setup of hydraulic wind power transfer systems. To maintain a fixed frequency electrical voltage by the system, the generator should remain at a constant rotational speed regardless of the wind speed. The fluctuating wind speed from the upstream, and the load variations from the downstream apply considerable disturbances on the system. A controller is designed and implemented to regulate the flow in the proportional valve and as a consequence the generator maintains its constant speed compensating for load and wind turbine disturbances. The control system is applied to the experimental prototype by utilizing MATLAB/Simulink and dSPACE 1104 fast prototyping hardware.

Utility Applications V

Wednesday, September 21, 3:30PM-5:10PM, Room: 202A, Chair: Olivier Trescases, Srdjan Lukic

**3:30PM***Field Upgradeable Transformer: A Fractionally-Rated Voltage Regulator for the Distribution System [#1401]*  
Rajendra Prasad Kandula, Hao Chen, Anish Prasai, Joe Schatz and Deepak Divan   
, Georgia institute of technology, United States; Varentec, Inc., United States; Southern Company, United States

The distribution system voltage volatility caused by changing load conditions and penetration of renewable resources presents an increasing challenge in the grid integration of renewables. This paper presents a novel voltage regulator, or field upgradeable transformer (FUT), for the distribution system, targeting at direct voltage regulation at the customer side with a fast dynamic response. Proposed system consists of a conventional medium voltage (MV) distribution transformer interfaced with a fractionally-rated power converter. Compared to other power electronics solutions for grid applications, the proposed device has advantages of low cost, high reliability, and high efficiency. The paper presents the FUT topology, principle of operation, control and protection scheme verified through simulation studies. Experimental results at 7.2 kV, 50 kVA, demonstrating FUT technology are also presented.

**3:55PM***New Configuration of Multi-Functional Grid-Connected Inverter to Improve Both Current-Based and Voltage-Based Power Quality [#1405]*  
Wooyoung Choi, Woongkul Lee, Di Han and Bulent Sarlioglu   
, University of Wisconsin-Madison, United States

In this paper, a new configuration of a multi-functional grid-connected inverter is proposed to improve both voltage-based and current-based power quality issue. By implementing bidirectional switches using semiconductor devices, a multi-functional grid-connected inverter can be connected in series or parallel to the grid and provides three modes of operation. This paper presents the control scheme of a multi-functional grid-connected inverter in each operating mode, the realization of bidirectional switches, and simulation results of the proposed multi-functional grid-connected inverter.

**4:20PM***Model Predictive Control of A Matrix-Converter Based Solid State Transformer for Utility Grid Interaction [#784]*  
Yushan Liu, Haitham Abu-Rub, Baoming Ge, Robert S. Balog and Yaosuo Xue   
, Texas A and M University at Qatar, Qatar; Texas A and M University, United States; Oak Ridge National Laboratory, United States

The matrix converter solid state transformer (MC-SST), formed from the back-to- back connection of two three-to-single-phase matrix converters, is studied for use in the interconnection of two ac grids. The matrix converter topology provides a light weight and low volume single-stage bidirectional ac-ac power conversion without the need for a dc link. Thus, the lifetime limitations of dc- bus storage capacitors are avoided. However, space vector modulation of this type of MC-SST requires to compute vectors for each of the two MCs, which must be carefully coordinated to avoid commutation failure. An additional controller is also required to control power exchange between the two ac grids. In this paper, model predictive control (MPC) is proposed for an MC-SST connecting two different ac power grids. The proposed MPC predicts the circuit variables based on the discrete model of MC-SST system and the cost function is formulated so that the optimal switch vector for the next sample period is selected, thereby generating the required grid currents for the SST. Simulation and experimental studies are carried out to demonstrate the effectiveness and simplicity of the proposed MPC for such MC-SST-based grid interfacing systems.

**4:45PM***A Triple Port Active Bridge Converter based Power Electronic Transformer [#912]*  
Venkat Nag Someswar Rao Jakka and Anshuman Shukla   
, Department of Electrical Engineering, IIT Bombay, India

Integration of multiple power sources using power electronic converters and high-frequency isolation links to supply the sustainable electricity is expected to have a significant impact on the future power system. In this paper, a triple port active bridge converter (TAB) based multi-fed power electronic transformer (TMF-PET) is proposed. The proposed PET consists of three ports having the flexibility to connect the power generating units, grid, and loads. The TMF-PET have three power conversion stages: input, isolation, and output. The input stage consists of two active rectifiers for integrating two different ac sources. The isolation stage consists of a triple port active bridge, and the output stage consists of an inverter. A detailed analysis of the principle of operation and the control techniques used for the converters of these stages are presented. The efficacy of the proposed system is verified using the simulation and experimental studies. The illustrated results show that the discussed controllers of TMF-PET are able to maintain the desired powers and voltages at the inputs and outputs of different power conversion stages. As a result, the proposed system can be used as an efficient energy router to interface different sources and loads in the modern power distribution systems.

Modeling, Analysis, and Control of Grid-Connected Converters IV

Wednesday, September 21, 3:30PM-5:10PM, Room: 202D, Chair: Paolo Mattavelli, John Lam

**3:30PM***Evaluation of Active Islanding Detection Based Methods Under Non-Liner-loads Scenarios [#805]*  
David Reigosa, Cristian Blanco, Juan Manuel Guerrero and Fernando Briz   
, University of Oviedo, Spain

Islanding detection has been the focus of significant research efforts during the last years. Islanding detection methods can be remote or local, the last being further divided into active and passive methods. Active methods have a reduced non-detection zone (NDZ) and ease of implementation. However they require the injection of some disturbing signal into the grid to measure its response, therefore having a negative impact on the power quality. High frequency signal injection islanding detection methods are a type of active methods that can be used both in single phase and three phase systems. While these methods have been demonstrated to be highly effective in different scenarios, including Single-inverter, Multi-inverter and Microgrid, the analysis reported so far only considered scenarios with linear loads. The proposed paper analyzes the use of high frequency signal injection based islanding detection methods in scenarios including non-linear-loads (NLLs) and active power filters (APFs). The presence of such elements can potentially interfere with the test signals injected for islanding detection; their impact on the method will be studied.

**3:55PM***Decentralized Adaptive Control for Interconnected Boost Converters based on backstepping approach [#1141]*  
Arturo Hernandez-Mendez, Jesus Linares-Flores and Hebertt Sira-Ramirez   
, Universidad Tecnologica de la Mixteca, Mexico; Centro de Investigacion y de Estudios Avanzados, Mexico

In this article, the local trajectory tracking control problems are reformulated as adaptive control problems. This approach gives rise to a robust decentralized solution, with virtually no information on local plants interaction dynamics. It is shown that when the interconnection effects are viewed as exogenous, unstructured, disturbances, such disturbance can be actively estimated and canceled from each individual subsystem model dynamics. The case presented deals with two interconnected boost DC-DC power converters feeding a time-varying current demand represented by a DC motor with uncertain load torque. Each subsystem is powered by a time-varying power supply. Additionally, we activate and deactivate both converters to verify the output voltage compensation and the inductor current distribution. The performance of the proposed controller is shown to be robust with respect to interaction, un-modeled nonlinearities, and un-modeled dynamics, that is demonstrated by experimental evidence.

**4:20PM***Impedance Synthesis by Inverter Control for Active Loads in Anti-Islanding Testbenches [#1553]*  
Tommaso Caldognetto, Luca Dalla Santa, Paolo Magnone and Paolo Mattavelli   
, University of Padova, Italy

This paper discusses the emulation of an active RLC load by means of an inverter. To this purpose, a suitable current control strategy is analyzed and developed. The limitations of this approach are explored, highlighting the requirements of the adopted regulator in order to avoid instability issues. The proposed analysis and model of the controlled system are verified by means of simulations and experimental tests on a 15 kVA prototype. The model is able to predict the presence of the resonant peaks closed to the current control bandwidth, thus giving useful guidelines to minimize such undesired effects. Finally, as a test case, the emulation of a resonant RLC load to be used in anti-islanding tests is considered.

**4:45PM***A Unified Impedance Model of Voltage-Source Converters with Phase-Locked Loop Effect [#1677]*  
Xiongfei Wang, Lennart Harnefors, Frede Blaabjerg and Poh Chiang Loh   
, Aalborg University, Denmark; ABB Corporate Research Center, Sweden

This paper proposes a unified impedance model for analyzing the effect of Phase- Locked Loop (PLL) on the stability of grid-connected voltage-source converters. In the approach, the dq-frame impedance model is transformed into the stationary frame by means of complex transfer functions and complex space vectors, which not only predicts the stability impact of the PLL, but reveals also its frequency coupling effect in the phase domain. Thus, the impedance models previously developed in the different domains can be unified. Moreover, the impedance shaping effects of PLL are structurally characterized for the current control in the rotating dq-frame and the stationary-frame. Case studies based on the unified impedance model are verified in the time-domain simulations and experiments.

More Electric Aircraft

Wednesday, September 21, 3:30PM-5:10PM, Room: 102D, Chair: Pat Wheeler, Bulent Sarlioglu

**3:30PM***An Induction Generator based Auxiliary Power Unit for Power Generation and Management System for More Electric Aircraft [#679]*  
Yijiang Jia and Kaushik Rajashekara   
, University of Texas at Dallas, United States

In more electric aircraft (MEA) systems, the adoption of electro-hydraulic actuators (EHAs) and electro-mechanical actuators (EMAs) requires a power- on-demand electrical power system with regenerative power management capability. This paper proposes an auxiliary power unit (APU) for power generation and management system to supply/absorb the highly dynamic power demand/regeneration from the EHA/EMAs. The proposed system utilizes an open- end winding induction starter/generator (OEWIS/G) to create a separate DC bus for the actuators without adding significant hardware installment to the system. During the entire flight mission, the regenerative power is recovered by one side of the OEWIG terminals; meanwhile, the power delivery to the main DC network of the aircraft electrical power system can be independently controlled by using the same generator through the other side of the terminals. A closed-loop control scheme based on field oriented control and instantaneous power theory is developed to regulate both the main DC bus voltage and the electric actuation DC bus voltage simultaneously in aircraft emergency power mode.

**3:55PM***Design and Optimization of a High Performance Isolated Three Phase AC/DC Converter for Aircraft Applications [#1334]*  
Qiong Wang, Xuning Zhang, Rolando Burgos, Dushan Boroyevich, Adam White and Mustansir Kheraluwala   
, CPES, Virginia Tech, United States; UTC Aerospace Systems, United States

This paper presents the design and optimization of a high performance isolated three- phase AC/DC converter that converts variable frequency 115 V AC voltage into isolated 28 V DC voltage. The main design target is to maximize converter rated power within given loss, size limitations and operation requirements. A two-stage structure, consisting of an active front-end (AFE) converter and an isolated DC/DC converter, is employed. To complete the design and optimization of the multi-converter system, a hierarchical design and optimization approach has been developed to explore the system loss-size Pareto front with considerations of thermal management, EMI performance and power quality. Methods for component optimization and loss calculation are introduced. Based on the design results (system loss-size Pareto front), a Vienna rectifier and an LLC resonant converter were selected for AFE and DC/DC stage respectively. Finally, a 1.2 kW convection cooled prototype was built and experimentally tested. It achieved 97.1% full load efficiency and 22 W/inch3 power density. Compliance with EMI and power quality standard was experimentally verified.

**4:20PM***Taking into account interactions between converters in the design of aircraft power networks [#1137]*  
Qian Li, Andrea Formentini, Arnaud Baraston, Xuning Zhang, Pericle Zanchetta, Jean-Luc Schanen and Dushan Boroyevich   
, CPES Virginia Tech, United States; University of Nottingham, United Kingdom; G2ELab - University Grenoble Alps, France

This paper presents some key interactions among converters, which need to be taken into account when designing a modern embedded electrical grid, including a large amount of Power Electronics based loads. A design by Optimization method is first used to define the converter parameters. During this step, it is mandatory to account for the interaction between the input and output EMI filters. The second step consists in designing the control strategy; the paper will show that the results are largely improved if all converters are considered simultaneously. Finally, the stability study of the embedded network has to be investigated. All these interactions are studied in the example of a three phases AC network, composed of a Voltage Source Inverter and an Active Front End.

**4:45PM***Stability Assessment of A Droop-Controlled Multi-Generator System in the More Electric Aircraft Using Parameter Space Approach [#743]*  
Fei Gao, Xiancheng Zheng and Serhiy Bozhko   
, The University of Nottingham, United Kingdom; Northwestern Polytechnical University, China

This paper investigates the dynamic stability of a droop-controlled multi-generator system in the more electric aircraft (MEA). Based on the developed state-space model of the potential dc electrical power system (EPS) architecture, the stability boundaries of EPS operation depending on parameter variations including component parameters and operating conditions are investigated. The effect of multiple parametric uncertainties on EPS stability is graphically illustrated by stability regions maps. In addition, the effect of the droop coefficient on the stability is discussed from the impedance point of view. The detailed mathematical models and analytical results of stability assessment are verified by time domain simulation studies.

DC-DC Converters: High Frequency

Wednesday, September 21, 3:30PM-5:10PM, Room: 102C, Chair: Seth Sanders, Juan Rivas-Davila

**3:30PM***A GaN-Based Partial Power Converter with MHz Reconfigurable Switched-Capacitor and RF SEPIC [#360]*  
Junjian Zhao and Yehui Han   
, University of Wisconsin-Madison, United States

This paper investigates a new reconfigurable switched-capacitor (SC) based partial power architecture which enhances the performance of radio frequency (RF) resonant DC/DC converters with gallium nitride (GaN) power devices. The proposed architecture has a comprehensive compatibility with existing RF and SC topologies and improves the performance of RF converters through partitioning of energy conversion stage and output regulation stage. Emerging new wide bandgap devices like GaN FETs enable a higher power density DC/DC converter design. A wider input range, larger voltage conversion ratio, smaller size, and excellent transient performance are expected. The prototype of the proposed GaN reconfigurable SC-based partial power RF converter comprises of a 20 MHz resonant single-ended-primary-inductor-converter (SEPIC) as a regulated stage and a high-efficiency 2 MHz reconfigurable SC as an unregulated stage. The GaN RF resonant SEPIC regulates the output using a robust ON/OFF control scheme, which enables fast transient responses. The high-efficiency GaN reconfigurable SC provides 1:1, 2:1 and 3:1 voltage conversion ratio which widens the input voltage range. The power stage of the prototype achieves a peak efficiency of 93 % and a power density of 963 W/in3 at 91.5 W.

**3:55PM***Monolithic Multilevel GaN Converter for Envelope Tracking in RF Power Amplifiers [#1448]*  
Alihossein Sepahvand, Parisa Momen Roodaki, Yuanzhe Zhang, Zoya Popovic and Dragan Maksimovic   
, University of Colorado at Boulder, United States

This paper presents a monolithic multilevel converter realized in a depletion-mode GaN process and intended to operate as a drain supply modulator (DSM) for high efficiency radio-frequency (RF) power amplifiers (PAs). The custom prototype chip includes a four-level power stage with on- chip integrated gate drivers and damping networks designed to mitigate effects of parasitics during output voltage level transitions. An optimization algorithm is described to maximize the drain supply system efficiency using the level voltages and a minimum switching interval as optimization variables. The monolithic multilevel chip is used to construct a four-level converter prototype. Experimental results are presented for tracking 8 MHz sine-wave and 10 MHz LTE envelope signals. The converter output voltage exhibits fast and well damped level-to-level transients. For the 10 MHz LTE envelope signal, the converter achieves greater than 97.3% power stage efficiency at 3.5W average output power level. Modern radio- frequency (RF) communications systems require power amplifiers (PAs) to process signals with high bandwidth and high peak-to-average power ratio (PAPR), which adversely affects PA efficiency. Efficiency improvement techniques include approaches based on drain supply modulation (DSM) or envelope tracking (ET). DSM based systems improve the efficiency of RF transmitters by dynamically adjusting the drain supply voltage of the PA in response to the RF envelope signal.

**4:20PM***An Improved PDM Control Method for a High Frequency Quasi-Resonant Converter [#967]*  
Hossein Mousavian, Alireza Bakhshai and Praveen Jain   
, Queen's University, Canada

This paper proposes a Pulse Density Modulation (PDM) method with improved transient for high frequency converters such as Class E DC/DC or quasi-resonant boost converters. In contrast to frequency or duty cycle control, the conventional PDM control method provides high efficiency at any load when modulation frequency is low. However, efficiency drops significantly for higher modulation frequencies due to the transient power losses in each power pulse. The proposed method decreases the power losses at the beginning of each pulse and reduces the voltage stress of the switch. Therefore, a higher modulation frequency and smaller filter size become feasible. Startup behavior of a quasi-resonant boost converter is analyzed in this paper. Soft switching conditions and peak voltage stress are studied as a function of the first switching cycle timing. In order to minimize the voltage overshoot and switching loss of the converter, the first switching period of each power pulse is chosen based on this analysis. A 1000 W, 3 MHz quasi-resonant boost converter with Class DE rectifier is implemented to verify the analysis and simulation results. A maximum efficiency of 96.7 percent is obtained. Further, the efficiency dropped less than three percent at one tenth of the load. About a 2% improvement in the light load efficiency is observed as compared to the conventional PDM method

**4:45PM***Automotive LED Driver Based On High Frequency Zero Voltage Switching Integrated Magnetics Cuk Converter [#1184]*  
Alihossein Sepahvand, Montu Doshi, James Patterson, Vahid Yousefzadeh, Khurram Afridi and Dragan Maksimovic   
, University of Colorado at Boulder, United States; Texas Instruments, United States

This paper presents a high-frequency zero voltage switching (ZVS) integrated-magnetics Cuk converter well-suited for automotive LED-driver applications. Input inductor, output inductor and the transformer are realized on a single magnetic structure, resulting in very low input and output current ripples, thus reducing EMI and the need for an output filter capacitor. Furthermore, the converter switching frequency is selected above the AM band to reduce radio frequency interference. Active-clamp snubbers are used to mitigate effects of the transformer leakage inductance. It is found that the active-clamp snubbers introduce substantial deviations in the steady-state operation of this converter when compared to a conventional Cuk converter. A numerical analysis technique is introduced to quickly evaluate the steady state behavior including the effects of non-linear transistor output capacitances on ZVS transitions. A prototype 1.8 MHz Cuk converter with integrated magnetics is designed, built and tested. The prototype converter supplies 0.5 A output current to a string of 1-to-10 LED's. It achieves 89.6 percent peak power-stage efficiency, and maintains greater than 80 percent overall efficiency across the wide output voltage range. In automotive lighting applications, light-emitting diodes (LEDs) with dc-dc drivers are rapidly displacing standard incandescent lamps. LED-based solutions offer longer lifetime, higher luminous efficacy, more natural monochromatic light (useful for headlights), faster turn on (advantageous in case of brake lights), as well as high-resolution PWM dimming and opportunities for more intelligent lighting such as adaptive headlights.

Modeling and Control of AC-DC Converters

Wednesday, September 21, 3:30PM-5:10PM, Room: 202E, Chair: Pragasen Pillay, Lixiang Wei

**3:30PM***Dynamic Response Optimization for Three-phase VIENNA Rectifier with Load Feedforward Control [#937]*  
Xudong Chen, Xiaoyong Ren, Zhiliang Zhang, Qianhong Chen and Xinbo Ruan   
, Nanjing Univ. of Aeronautics and Astronautics, China

This paper proposes a load feedforward digital control scheme to optimize dynamic response of three-phase Vienna rectifier. The transient state of voltage loop in conventional average current mode control is analyzed in detail. In order to reduce overshoot of output voltage, load feedforward control is utilized to compensate voltage loop. The terms of feedforward compensator are derived assuming ideally balanced grid and unity power factor. The moment of load step is detected to increase response speed. To avoid addition distortion to line current waveform, the proposed feedforward variable is only updated at transient and keep constant in steady state. Frequency domain response characteristics are analyzed. Simulation models demonstrate the proposed control strategy and a prototype of 3kW Vienna rectifier is built based on DSP TMS320F2808 development board.

**3:55PM***A Compensation Scheme to Reduce Input Current Distortion in GaN Based 450 kHz Three-Phase Vienna Type PFC [#1544]*  
Bo Liu, Ren Ren, Edward Andrew Jones, Fred Wang, Daniel Jes Costinett and Zheyu Zhang   
, the University of Tennessee, United States

Wide bandgap (WBG) semiconductors owing to their low loss and high switching capability, are gradually adopted in high power-density high efficiency applications, and impose new challenges from control to hardware design. In this paper, a Gallium Nitride (GaN) HEMT plus SiC diode based Vienna type rectifier is proposed to serve as the power factor correction stage for a high-density battery charger system. To meet low current harmonic requirement, PWM voltage distortion during turn-off transition, found as the main harmonics contributor, is studied. The distortion mechanism led by different parasitic capacitances of WBG devices is presented. A mitigation scheme is thereafter proposed considering their nonlinear voltage-dependent characteristics and eventually deduced from a pulse- based turn-off compensation to a generic modulation correction. Simulation and experimental results through a 450 kHz enhancement-mode GaN based Vienna type rectifier finally demonstrate the high performance of the proposed approach, showing a THD reduction up to 7% with a relatively low-speed control.

**4:20PM***Modeling and Analysis for Input Characteristics of Line-Frequency Rectifiers [#803]*  
Xiaolong Yue, Dushan Boroyevich, Rolando Burgos and Fang Zhuo   
, Xi'an Jiaotong University, Virginia Tech, China; Virginia Tech, United States; Xi'an Jiaotong University, China

Impedance is very important for power electronic systems because of the close relationship between impedance and system stability. The line- frequency rectifiers are commonly used ac-dc interfaces in electrical power systems. For line-frequency rectifier, with a sinusoidal voltage perturbation excitation at input terminal, input current contains not only perturbation frequency, but also multiple additional frequency components. Therefore, input characteristics of line-frequency rectifiers are actually single input multiple output (SIMO) in frequency domain. However, in tradition, input current perturbation is simplified into a sinusoidal signal at perturbation frequency by ignoring other additional frequency components and the obtained impedance models mainly focus on frequency regions below line frequency. To describe the SIMO input characteristics of line-frequency rectifiers and to develop an impedance model that could be applied beyond switching frequency, this paper proposes a new model by using harmonic balance method. Detailed analysis indicates that input admittance of line frequency rectifier in high frequency regions acts like a resistor rather than inductor. The simulations validate the accuracy and effectiveness of the proposed model.

**4:45PM***Hybrid Damping for Active Front End Converter [#1552]*  
Yogesh Patel, Sayed Ahmed Ahmed and Lixiang Wei   
, Rockwell Automation, United States

The AFE converter is usually connected to the grid through an LCL filter. In this paper, a hybrid technique is introduced to damp the resonance condition that may result due to the existence of the LCL filter. This technique relies on the concept of hybrid damping which combines the advantages of both active and passive damping previously introduced in literature. It will also be shown that the introduced technique overcomes previous limitations which renders this technique more practical and highly applicable to reliable industrial products.

Converter Control in Microgrids and Distributed Generation

Wednesday, September 21, 3:30PM-5:10PM, Room: 203DE, Chair: Leon M Tolbert, Shu-hung Chung

**3:30PM***A Feed-forward Based Harmonic Compensation Approach for Low Switching Frequency Grid Interfacing VSI [#789]*  
Hao Tian and Yun Wei Li   
, University of Alberta, Canada

Embedding voltage harmonic compensation function in Distributed Generation (DG) systems is a promising solution for the increasing concern about power quality in distribution grid. This paper focuses on adding harmonic compensation function to these low switching frequency DG systems and applies a current feed forward method to overcome the bandwidth limit in their feedback control loop. The complex feed forward gain is designed based on the virtual impedance theory. By applying discrete modeling method, the zero- order-hold characteristics of low switching frequency PWM are accurately modeled. The stability analysis in z domain is also given to verify its applicability and advantage in stability. Finally, the good compensation performance is validated by experiment results.

**3:55PM***An Embedded Voltage Harmonic Compensation Strategy for Current-Controlled DG Interfacing Converters [#1233]*  
Xin Zhao, Lexuan Meng, Chuan Xie, Josep Guerrero, Mehdi Savaghebi, Juan Vasquez and Xiaohua Wu   
, Aalborg University, Denmark; Aalborg university, Denmark; University of Electronic Science and Technology, China; Northwestern Polytechnical University, China

Harmonics has been considered as one of the major issues in future power grids. With the increasing demand in advanced control functions, power electronic interfaced distributed generators are expected to perform harmonic compensation when necessary. It has been demonstrated in a number of studies that DG converters operating in Voltage-Controlled Mode (VCM) can be easily configured to realize voltage harmonic suppression utilizing naturally embedded voltage control loop. While for DG converters operating in Current-Control Mode (CCM), such function was rarely studied. Considering CCM is commonly used in renewable energy based generators and energy storage systems, is has certain significance the same function with CCM operated converters. Aiming at such objective, this paper proposes a voltage detection based embedded Harmonic Compensator (HC) for CCM converters. The novelty and main advantages of the proposed method include: 1) it realizes seamless interface of HC with inner fundamental current loop 2) compared with conventional active filtering method, it does not require remote load harmonic current measurement 3) compared with conventional voltage detection based method, it offers better performance because of direct harmonic voltage regulation. Experimental results are presented to demonstrated the effectiveness of the method.

**4:20PM***Analysis and Damping of harmonic propagation in DG-Penetrated distribution networks [#751]*  
Jinghang Lu, Mehdi Savaghebi and Josep Guerrero   
, Aalborg University, Denmark

With the increasing penetration of nonlinear loads into distribution system, stable operation of power distribution system suffers challenge by harmonic voltage propagation and resonance amplification which is also known as whack-a- mole phenomenon. However, until now this phenomenon has not been well investigated and discussed. This paper starts from theoretical analysis of harmonic propagation and how it is triggered when DG unit interfaced to the grid. Moreover, harmonic damping performance of various types of impedance seen from DG at selected frequencies are analyzed and compared by introducing microwave transmission line theory. In addition, this paper proposes a control algorithm with DG unit where virtual impedances at selected frequencies are individually designed to mitigate the harmonic amplification. The validity of the control strategy has been verified by the case study results.

**4:45PM***Voltage and Current Regulators Design of Power Converters in Islanded Microgrids based on State Feedback Decoupling [#1130]*  
Federico de Bosio, Luiz Antonio de Souza Ribeiro, Francisco Freijedo, Josep Guerrero and Michele Pastorelli   
, Politecnico di Torino, Italy; Federal University of Maranhao, Brazil; Ecole Polytechnique Federale de Lausanne, Switzerland; Aalborg University, Denmark

In stand-alone microgrids based on voltage source inverters state feedback coupling between the capacitor voltage and inductor current degrades significantly the dynamics performance of voltage and current regulators. The decoupling of the controlled states is proposed, considering the limitations introduced by system delays. Moreover, a proportional resonant voltage controller is designed according to Nyquist criterion taking into account application requirements. Experimental tests performed in compliance with the UPS standards verify the theoretical analysis.

Reliability, Diagnostic and Faults Analysis in Power Converters II

Wednesday, September 21, 3:30PM-5:10PM, Room: 102E, Chair: Marco Liserre, Lee Empringham

**3:30PM***Computation and Analysis of Dielectric Losses in MV Power Electronic Converter Insulation [#1083]*  
Thomas Guillod, Raphael Faerber, Florian Krismer, Christian M. Franck and Johann W. Kolar   
, Power Electronic Systems Laboratory (PES), ETH Z, Switzerland; High Voltage Laboratory, ETH Zurich, Switzerland

The newly available Medium Voltage (MV) Silicon-Carbide (SiC) devices enable a great extension of the design space of MV inverters. This includes the utilization of unprecedented blocking voltages, higher switching frequencies, higher commutation speeds, and high temperature operation. However, all these factors considerably increase the insulation stress. This paper details the computation of dielectric losses, which are directly related to the insulation stress and can be used for the insulation design and diagnostic. After a review of the method used to compute dielectric losses, scalable analytical expressions are derived for the losses produced by PWM waveforms of DC-DC, DC-AC, and multilevel DC-AC inverters. Finally, a Medium-Frequency (MF) transformer is analyzed and the impacts of the insulation material and the operating temperature on the dielectric losses are discussed. It is found that the insulation losses can represent a significant share (17 %) of the total transformer losses.

**3:55PM***Computational Light Junction Temperature Estimator for Active Thermal Control [#645]*  
Markus Andresen, Mike Schloh, Giampaolo Buticchi and Marco Liserre   
, Christian-Albrechts-University Kiel, Germany

The junction temperature of power semiconductors in power converters must not exceed its maximum limits and it is of major importance for several failure mechanisms. But still, the junction temperature is hard to access. Direct measurement is not practical for industrial applications, indirect measurements require substantial effort and available junction temperature models have high calculation effort. This work develops a simple junction temperature estimator, which is applied for a maximum junction temperature limitation and the capability to be applied for further algorithm relying on the junction temperature, referring to active thermal control. It is experimentally shown, that a second order estimator is sufficient to achieve high bandwidth estimation.

**4:20PM***Fast Fault Diagnosis and identification Method for Boost Converter Based on Inductor Current Emulator [#1381]*  
Elham Pozouki, Alexis De Abreu-Garcia and Yilmaz Sozer   
, University of Akron, United States

This paper proposes a fault diagnosis and identification method for non-isolated dc-dc converters. The method can detect the fault and identify the faulty switch, and switch fault type, in less than one switching cycle. The main idea is to apply the derivative of the inductor current, based on the modulation of the particular dc-dc converter, to provide a predictive current emulator model. The measured inductor current and its corresponding predicted current are used to diagnose the switch fault. The method, implemented on a DSP, is robust to common converter asymmetry such as load variations, input disturbances, etc. The proposed fault diagnosis method has been analyzed, tested, and validated for a boost converter.

**4:45PM***Modeling and Improvement of Thermal Cycling in Power Electronics for Motor Drive Applications [#1561]*  
Ionut Vernica, Ke Ma and Frede Blaabjerg   
, Aalborg University, Denmark

It is well known that the dynamical change of the thermal stress in the power devices is one of the major factors that affects the overall efficiency and reliability of power electronics. The main objective of this paper consists of identifying the main parameters that affect the thermal cycling of power devices in a motor drive application and highlighting their impact on the thermal stress. The motor drive system together with the thermal cycling in the power semiconductors have been modelled, and after investigating the dynamic behaviour of the system, adverse temperature swings could be noticed during the acceleration and deceleration periods of the motor. The main causes for these adverse thermal cycles have been presented and, consequently, the influence of the deceleration slope, modulation technique and reactive current on the thermal cycles has been analyzed. Finally, the improved thermal response of the power devices is validated through experimental results.

Reliability and Fault Tolerance in Multilevel Converters

Wednesday, September 21, 3:30PM-5:10PM, Room: 202B, Chair: Sheldon Williamson, Christian Klumpner

**3:30PM***Highly Reliable Transformerless Neutral Point Clamped Inverter with Separated Inductors [#1519]*  
Liwei Zhou, Feng Gao, Guang Shen and Mengxing Chen   
, Shandong University, China; State Grid Rizhao Power Supply Company, China

In the transformerless grid connected photovoltaic system, the inverter is the main component. In order to improve the efficiency of the inversion system and achieve a low level of leakage current, several topologies have been applied, among which three level NPC inverter is a kind of popular application. Because the three level NPC inverter has the advantages of low switching losses, good common mode behavior and the small output distortion. This paper proposed a kind of novel three level half bridge NPC inverter with high reliability. The topology only assumes four switches and two diodes with a constant common mode voltage. More importantly, compared to the traditional half bridge NPC inverter, the proposed topology can avoid the shoot through problem without adding the dead time. Also, the novel topology has a lower conduction losses compared to most of the NPC half bridge inverters and the dual buck typed half bridge inverters. The common mode model and the operating principles of the novel topology is analyzed which has verified the advantages. Meanwhile, the three phase structure of the proposed topology is introduced to further illustrate the applications. Finally, the simulation and experimental results illustrated the theoretical findings.

**3:55PM***Fault Detection and Tolerant Control of Open-circuit Failure in MMC with Full-bridge Sub-modules [#1306]*  
Kai Li, Zhengming Zhao, Liqiang Yuan, Sizhao Lu and Ye Jiang   
, Dept. Electrical Engineering, Tsinghua Univ., China

Modular multilevel converter (MMC) has drawn tremendous attention since its invention. It is usually composited by a large number of sub-modules, which makes the reliability as one of the most important challenges for MMC. Besides, due to the DC side short- circuit blocking and ride-through capability, MMC with full-bridge SMs is very competitive. Considering the IGBT open-circuit failure in MMC with full-bridge SMs, the fault features are analyzed in detail in this paper. Then a complete set of fault detection and tolerant control strategy is proposed. The feasibility and effectiveness of the proposed fault detection and tolerant control strategy have been confirmed through the simulations in MATLAB/Simulink.

**4:20PM***Control Strategy of Single Phase Back-to-back Converter for Medium Voltage Drive under Cell Fault Condition [#1341]*  
Yoon-Ro Lee, Jeong-Mock Yoo, Hyun-Sam Jung and Seung-Ki Sul   
, Seoul National University, Korea (South)

Cascaded H-Bridge (CHB) inverter is the most widely used topology for Medium Voltage (MV) drive system due to the high degree of modularity, easier implementation of medium output voltage, and ability to continuous operation under the cell fault condition. Because each power cell of CHB should have isolated DC source, multi- winding input transformer and three phase Active Front-End (AFE) are generally used for regenerative applications. The whole system can be reduced by replacing the three phase AFE with single phase AFE. However, input power imbalance among three phases under the cell fault condition inevitably occurs, if control strategy of normal operation is employed in system. This paper proposes a control scheme for the cell fault condition of single phase AFE CHB. Not only DC-link voltages of each cell but also grid current are regulated well without imbalance by applying the proposed control scheme to the system, even in the cell fault condition. Simulation and experimental results are provided to verify the effectiveness of the proposed scheme.

**4:45PM***Fault Tolerance Analysis for the 5-Level Unidirectional T-Rectifier [#182]*  
Alessandro Lidozzi, Marco Di Benedetto, Luca Solero, Fabio Crescimbini and Petar Grbovic   
, ROMA TRE University, Italy; Huawei Technologies, Germany

This paper deals with the fault tolerance analysis applied to the converter topology 5-level unidirectional T-Rectifier (5L T-RECT) to be used for electric generating applications. The proposed generating unit is intended for aerospace applications with high fundamental electric frequency, to this purpose the investigated power electronic converter configuration is able to supply power to the electric loads at different voltage levels. The depicted analysis has been performed to show the 5L T-RECT behavior in case of either switch or diode fault; identification and consequent action to be taken are shown in order to guarantee the converter continued operation.

Electric Machines for Automotive Applications III

Wednesday, September 21, 3:30PM-5:10PM, Room: 102B, Chair: Julia Zhang, Jie Shen

**3:30PM***Design of a Wound Field Synchronous Machine for Electric Vehicle Traction with Brushless Capacitive Field Excitation [#1099]*  
Antonio Di Gioia, Ian P. Brown, Ryan Knippel, Daniel C. Ludois, Yue Nie, Jiejian Dai, Skyler Hagen and Christian Alteheld   
, Illinois Institute of Technology, United States; University of Wisconsin-Madison, United States; Duesseldorf University of Applied Sciences, Germany

This paper describes the modeling, optimization, mechanical design, and experimental characterization of a high power density wound field synchronous machine (WFSM) for electric vehicle traction applications. The WFSM is designed for brushless rotor field excitation using an axial flux hydrodynamic capacitive power coupler (CPC). A flexible design environment is described which was used for large scale multi-objective optimization. A prototype WFSM, spray cooled with automatic transmission fluid (ATF), with an 80 kW (peak) output at a base speed of 4,000 RPM has been tested. The prototyped WFSM achieves peak volumetric and specific torque and power densities of 17.22 Nm/l, 4.69 Nm/kg, 7.19 kW/l, and 1.95 kW/kg.

**3:55PM***Design and Development of a MLS Based Compact Active Suspension System, Featuring Air Spring and Energy Harvesting Capabilities [#573]*  
Nick Ilsoe Berg, Rasmus Koldborg Holm and Peter Omand Rasmussen   
, Aalborg University, Denmark

This paper describes the design and development of an novel Magnetic Lead Screw based active suspension system for passenger vehicles, using a new MLS topology. The design is based on performance specifications found from ISO road profiles, with a maximum harvested energy approach. By integrating the PMSM motor with the MLS, it possible to construct a very compact design with an integrated air spring. The prototype is build and frictional losses and efficiency for the MLS damper unit are measured. Additional the stall force and stall torque are measured for the build prototype to validate the developed 3D FEM model. It was concluded that the MLS damper unit was capable of delivering a mean efficiency of up to 80% for a full up and down stroke (+/- 48 mm).

**4:20PM***A Simple Design Method for Surface-mounted PM machines for Traction Application [#673]*  
Chao Lu and Gianmario Pellegrino   
, Politecnico di Torino, Italy

Surface-mounted permanent magnet motors with concentrated windings (CW-SPM) can have a wide constant power speed range if properly designed. This study introduces a design approach for CW-SPM machines for traction application, presenting the new parametric design plane x, b, where x accounts for the rotor on stator radius split and b summarizes the share between copper and iron in the stator. The proposed design method aims at covering the important area of design of PMSMs with flux weakening capability, with a simple methodology. Analytical and finite-element (FEA) models are used jointly. The design flowchart is illustrated and the output designs are validated by FEA. All presented results are obtained through open-source design resources available online.

**4:45PM***Design Optimization of Spoke-Type PM Motors for Formula E Racing Cars [#1283]*  
Alireza Fatemi, Dan Ionel, Mircea Popescu and Nabeel Demerdash   
, Marquette University, United States; University of Kentucky, United States; Motor Design Ltd, United Kingdom

This paper presents the performance trade-offs in the design optimization of spoke-type permanent magnet (PM) motors for high speed and very high torque density traction motors. An example 18-slot 16-pole machine for a direct drive Formula E race car over the Le Mans driving cycle is considered. Both low speed and extended speed/field-weakening operations are evaluated using high fidelity finite element (FE) simulations, to simultaneously increase the torque density and decrease the power losses over the high energy- throughput zones of the machine torque-speed plane. The results of the design optimization process yielding 3,400 design candidates are utilized to quantify the performance trade-offs for increasing the power density in spoke-type PM motors. These trade-offs include the impacts on other performance metrics such as power losses, PM demagnetization, and torque ripple. The analysis is supplemented by multi-physics simulation of three counterpart optimized designs, and successful experimental verification of a prototype of one of those three designs which represents a record high power density motor in traction applications.

PM Machines IV

Wednesday, September 21, 3:30PM-5:10PM, Room: 101A, Chair: Leila Parsa, Radu Bojoi

**3:30PM***Tolerance Study to Forecast Performances of Permanent Magnet Synchronous Machines Using Segmented Stator for Mass Production [#1624]*  
TaeSik Kim, Mazharul Chowdhury, Mohammad Islam, Abraham Gebregergis and Tomy Sebastian   
, Halla Mechatronics, United States

This research provides a detailed analysis of build variations for mass produced permanent magnet synchronous motors on key performances such as torque ripple, and back-emf harmonics. The study defines the rule for worst case scenarios hence provide tolerance limits for each of the design parameters to be controlled to achieve certain performances under volume production. The research also sorts out the sources for each torque ripple order. A finite element based electromagnetic simulation is used for the tolerance study and effectively used for defining realistic limits for key design parameters. The motors were built and tested to verify the theories which showed strong correlation and justify the values of such study before launching volume production.

**3:55PM***Permanent Magnet Material and Pulsating Torque Minimization in Spoke Type Interior PM Machines [#146]*  
Zhentao Stephen Du and Thomas Anthony Lipo   
, Dept. of ECE Wisconsin-Madison, United States

This paper proposes an alternative spoke type interior permanent magnet machine design to minimize the pulsating torque and decrease the use of permanent magnet materials. The proposed rotor design consists of a number of rotor lamination stacks with notches made on the surface and packed in the axial direction. Within each stack, the width of the permanent magnets (PMs) and the span of the notches are different from those in the other lamination stacks. The design has optimized and verified by 2D finite element and its performance was compared against the 2007 Camry motor model. The results demonstrate improvement in the pulsating torque and the PM material utilization of the proposed model.

**4:20PM***Mechanical Design Method for a High-Speed Surface Permanent Magnet Rotor [#1399]*  
Erik Schubert and Bulent Sarlioglu   
, University of Wisconsin-Madison, United States

Mechanical design of the rotor is an important part of the design process for high-speed electric machines. This paper proposes an analytical method for finding an approximate rotor length and diameter for a surface permanent magnet machine rotor early in the design process. Specifically, the method can be used to find approximate rotor length and diameter dimensions that will balance the need for acceptable factor of safety for rotor sleeve stress and the need for an acceptable separation margin between the operating and critical speeds. Analytical design results are compared to finite element analysis for both the mechanical stress and the natural frequency of the rotor.

**4:45PM***Analysis and Design of Triple-Rotor Axial-Flux Spoke-Array Vernier Permanent Magnet Machines [#928]*  
Rui Zhang, Jian Li, Ronghai Qu and Dawei Li   
, Huazhong University of Science and Technology, China

This paper presents a triple-rotor axial-flux spoke-array vernier permanent magnet (TR-AFSAVPM) machine to enhance the performance of vernier machines. By cooperating spoke-array rotor and coil-wounded winding, power factor and torque density of the proposed machines are much improved and their copper utilization is reduced as well comparing with conventional vernier machines. Firstly, the machine structure and operation principles are introduced. After that, analytical equations of the machine back-EMF and torque are derived to reveal its features. Based on both quasi-3D finite element analysis (FEA) and 3D-FEA, its high torque density performance is verified and a set of optimized machine sizing specifications is ultimately settled. A fractional slot axial-flux permanent magnet machine and an axial-flux surface vernier permanent magnet machine are designed to compare with the proposed machine. Analysis results show that the TR-AFSAVPM machine has high power factor, viz. 0.97 and high torque density, viz. 24.2kNm/m3. A prototype has been designed and is being manufactured to validate the results.

Energy Efficient Motor Drives

Wednesday, September 21, 3:30PM-5:10PM, Room: 101B, Chair: Francisco Canales, Dong Jiang

**3:30PM***Electrical Loss Minimization Technique for Wind Generators based on a Comprehensive Dynamic Modelling of Induction Machines [#136]*  
Maria Carmela Di Piazza, Massimiliano Luna and Marcello Pucci   
, ISSIA-CNR, Italy

This paper proposes a novel model-based electrical losses minimization technique (ELMT), whose main original contribution lies in the overall power losses function which has been derived from a comprehensive dynamic space-vector model of the IM including the iron losses, expressed in the rotor flux oriented reference frame. Such a losses formulation, obtained from the IM input-output power balance, reveals more general and accurate than the others in literature and consequently the expression of the optimal efficiency reference flux to be given to the FOC control system is more general and accurate too. The proposed ELMT has been integrated in an IM-based wind generation system including a previously developed GNG-based MPPT. Results show that the new formulation of the overall power losses of the IM permits an increase of the IM efficiency up to 4% with respect to the classic loss equation proposed in scientific literature. The integration of the proposed ELMT in a real wind generation system leads to an increase of the active power injected into the power grid ranging from 33% at high wind speeds up to 200% at low wind speeds.

**3:55PM***Maximum Efficiency Control Method in 7-phase BLDC Motor by Changing the Number of the Excited Phase Windings [#303]*  
Sang-Woo Park, Hyung-Seok Park, Jong-Joo Moon, Won-Sang Im and Jang-Mok Kim   
, LG Electronics, Korea (South); Pusan National University, Korea (South); Lehigh University, United States

This paper proposes a maximum efficiency control method in 7-phase brushless DC motors (7-phase BLDCMs) used for the ship propulsion system. In the same load condition, the electrical loss of the 7-phase BLDCM is dependent on the number of the excited windings and the instantaneous phase currents. Thus, it is necessary to determine the excitation number of the phase windings according to the load condition. The 2- and 4-phase excitation methods are proposed for the maximum efficiency operation. The phase excitation method of the minimum system loss according to the load condition can be obtained from the loss analysis. In addition, by using the loss analysis, the optimal speed which is the changing point of the phase excitation to select the optimal excitation methods (2-, 4- and 6 and 6-phase excitation) can be calculated and derived. The proposed method can be easily implemented by controlling the conductive angle of the phase current at the suitable phase windings. The maximum efficiency operation can be achieved by using the proposed excitation method and 6-phase excitation method. The usefulness of the proposed control algorithm is verified through simulation results.

**4:20PM***Control Strategy for Dual Three-Phase PMSMs With Minimum Losses in the Full Torque Operation Range Under Single Open-Phase Fault [#578]*  
Fernando Baneira, Jesus Doval-Gandoy, Alejandro Yepes, Oscar Lopez and Diego Perez-Estevez   
, University of Vigo, Spain

Fault tolerance is an advantageous characteristic of multiphase machines when compared with three-phase ones. During open-phase fault, the current references need to be adapted to provide ripple-free torque. As a consequence of this modification, the post-fault phase currents might be larger than the rated current. Such situation leads to overheating, and to preserve the integrity of the system, some limits are set to the post-fault phase currents. Two main strategies have been proposed for the post-fault situation: maximum torque (MT) and minimum losses (ML). The MT strategy allows to obtain the widest torque operation range (TOR) in the post-fault situation but does not minimize the stator winding losses; conversely, the ML strategy provides the minimum stator winding losses for each torque value, at the expense of reducing the TOR. Thus, the solutions proposed so far do not achieve minimum stator winding losses in the entire (that of the MT strategy) TOR. This paper presents the full-range minimum losses (FRML) post-fault control strategy, which minimizes the losses in the whole TOR, for dual three-phase permanent-magnet synchronous machines with sinusoidally distributed windings under single open-phase fault. Experimental results are provided.

**4:45PM***A Multi-Pulse Front-End Rectifier System with Electronic Phase-Shifting for Harmonic Mitigation in Motor Drive Applications [#1158]*  
Firuz Zare, Pooya Davari and Frede Blaabjerg   
, The University of Queensland, Australia; Aalborg University, Denmark

In this paper, an electronic phase-shifting strategy has been optimized for a multi-parallel configuration of line-commutated rectifiers with a common dc- bus voltage used in motor drive application. This feature makes the performance of the system independent of the load profile and maximizes its harmonic reduction ability. To further reduce the generated low order harmonics, a dc-link current modulation scheme and its phase shift values of multi-drive systems have been optimized. Analysis and simulations have been carried out to verify the proposed method.

Sensorless Drives II

Wednesday, September 21, 3:30PM-5:10PM, Room: 101CD, Chair: Fernando Briz, Giacomo Scelba

**3:30PM***A Robust Magnetic Polarity Self-Sensing Method for Start-Up of PM Synchronous Machine in Fan-Like System [#327]*  
Wei Sun, Jian-Xin Shen, Meng-Jia Jin and He Hao   
, Zhejiang University, China

In the field of permanent magnet synchronous motor (PMSM) self-sensing control, the initial rotor position estimation is always important, for which, the rotor magnetic polarity estimation is particularly a major task. This paper presents a robust rotor polarity estimation method based on the comprehensive utility of both magnetic saturation effect and rotor angular acceleration. The method can be used for the PMSM system for the fan or pump-like applications. In the method, pulsating-voltage-vector injection is used to track the d-axis and measure the incremental inductance variation of the estimated d-axis. The magnetic saturation effect is magnified by exciting a sinusoidal low-frequency d-axis current rather than the traditional DC current. The angular acceleration is then measured by exciting a positive ramp q-axis current. Both the incremental inductance variation and the angular acceleration contain the rotor polarity information. In this paper, these two methods are combined, as the latter method is to confirm the estimation of the former method. Thus, a robust self-sensing start-up is guaranteed. Experimental results validate the effectiveness of the proposed algorithm.

**3:55PM***Universal Sensorless Vector Control Applicable to Line-Start Permanent Magnet Synchronous Motors with Damper Winding [#1006]*  
Shu Yamamoto, Hideaki Hirahara, Akira Tanaka and Takahiro Ara   
, Polytechnic University, Japan; Kanto Polytechnic College, Japan

This paper proposes an improved Universal Sensorless Vector (USV) control which can drive not only induction motor and damperless Permanent Magnet Synchronous Motor (PMSM) but also Line-Start PMSM with damper winding (LS-PMSM) by a unified control algorithm without a position/speed sensor. The reason why the step-out problem occurs when the conventional USV control is employed to operate the LS-PMSM is investigated and clarified. As a result, it is found that, by only adding a low pass filter to the load angle calculator to suppress the high-frequency vibration of the estimated load angle, the step-out problem is completely removed and the USV control becomes applicable to the LS-PMSM. The validity of the proposed method is demonstrated with experimental results on a 0.5-kW, 4-pole, 1500-r/min LS-PMSM.

**4:20PM***Improvement of Back-EMF Self-Sensing for Induction Machines when using Deadbeat-Direct Torque and Flux Control (DB-DTFC) [#662]*  
Kang Wang, Noor Baloch and Robert Lorenz   
, University of Wisconsin - Madison, United States; Yaskawa Electric Corporation, Japan

Back-EMF self-sensing is commonly used in induction machine (IM) drive systems for its maintenance cost and safety considerations. In recent years, deadbeat- direct torque and flux control (DB-DTFC) has been shown to be a highly effective method for induction machine control. It has advantages such as the fastest possible torque dynamics, dynamically loss manipulation capability independent of torque dynamics, and parameter insensitivity. This paper evaluates the synergy between back-EMF self-sensing technology and DB-DTFC for IM drive systems. In this paper, an observer-based closed-loop back-EMF tracking self-sensing control in an IM DB-DTFC drive system is presented. It includes a back-EMF state filter, back-EMF tracking observer, and cascaded motion observer. Back-EMF harmonic decoupling is explored to improve the low speed performance. The bandpass filter method (BPF) for back-EMF self-sensing is also presented. Finally, the closed loop system dynamic stiffness at very low speeds, with and without the BPF method, is experimentally evaluated.

**4:45PM***Sensorless Position Control of PMSM Operating at Low Switching Frequency for High Efficiency Climate Control Systems [#1578]*  
Parag Kshirsagar and R. Krishnan   
, United Technologies Research Center, United States; Virginia Polytechnic and State University, United States

Low switching frequency operation is preferred to improve the system efficiency as well as for optimal use of inverter rating in variable speed drive systems. Low switching frequency operation presents stability and performance issues during transition from lower to higher speed operations using asynchronous to synchronous programmed pulse width modulation (PWM) operation of the inverter. The paper presents a sensorless vector control strategy for the permanent magnet synchronous motor (PMSM) drive operating at low switching frequency with programmed PWM methods. Specifically for the reduced switching frequency operation, the analysis, design and implementation of the key control subsystems consisting of the current controller, back EMF observer and position tracking controller in the drive system are developed and presented. Experimental results validate the design methodology, system performance including the efficiency improvement with the proposed control strategy.

Silicon and WBG Devices

Wednesday, September 21, 3:30PM-5:10PM, Room: 202C, Chair: Jerry Hudgins, Enrico Santi

**3:30PM***SuperJunction Cascode, a Configuration to Break the Silicon Switching Frequency Limit [#797]*  
Juan Rodriguez, Jaume Roig, Alberto Rodriguez, Ignacio Castro, Diego G. Lamar and Filip Bauwens   
, Power Supply System Group, University of Oviedo, Spain; Power Technology Centre, ON Semiconductor, Belgium

This paper evaluates the SuperJunction MOSFET in cascode configuration with a low-voltage silicon MOSFET. The structure combines the good switching performance provided by the cascode configuration with advantages of the silicon technology as the robustness, the maturity and the low-cost. The objective of this paper is to elucidate and to demonstrate the reduction of switching losses of SuperJunction MOSFETs in cascode configuration with respect to their standalone counterparts (directly driven). A detailed simulation analysis of power loss contributions is carried out under hard-switching operation. Eventually, experimental evidence is provided by using a boost converter (100 V-to-400 V) in continuous conduction mode for a wide range of switching frequency (100 kHz-to-400 kHz) and output power (180W-to-500W).

**3:55PM***Maximizing the Performance of 650 V p-GaN Gate HEMTs: Dynamic Ron Characterization and Gate-Drive Design Considerations [#538]*  
Hanxing Wang, Ruiliang Xie, Cheng Liu, Jin Wei, Gaofei Tang and Kevin. J Chen   
, Hong Kong University of Science and Technology, Hong Kong

This paper presents a systematic characterization of a 650 V/13 A enhancement- mode GaN power transistor with p-GaN gate. Static and dynamic device characteristics are measured by taking into account of trapping induced effects such as current collapse and threshold voltage instability. Switching performance is evaluated up to 400 V, 10 A using a custom designed double- pulse test circuit. Optimal gate drive conditions are proposed to minimize the influence of adverse trapping effects on circuit performance while preventing the device from excessive gate stress. Moreover, gate drive circuit design and board layout considerations addressing the fast switching characteristics of GaN devices are also discussed.

**4:20PM***15kV/40A FREEDM Super-Cascode: A Cost Effective SiC High Voltage and High Frequency Power Switch [#834]*  
Xiaoqing Song, Alex Huang, Zhang Liqi, Liu Pengkun and Xijun Ni   
, North Carolina State Univeristy, United States; North Carolina State University, United States; Nanjing Institute of Technology, China

High voltage wide bandgap (WBG) semiconductor devices like the 15kV SiC MOSFET have attracted great attentions because of its potential applications in high voltage and high frequency power converters. However, these devices are not commercially available at the moment and their high cost due to expensive material growth and fabrication may limit their widespread adoption in the future. In this paper, a 15kV/40A three terminal power switch, the FREEDM Super-Cascode, is reported for the first time which is based on series connection of 1.2kV SiC power devices. The design and operation principle of the FREEDM Super-Cascode are introduced and the performance including the static blocking capability, conduction characteristics over a wide range of temperatures, and dynamic switching performances are analyzed. In addition, the thermal resistance of the FREEDM Super-Cascode is measured and the power dissipation capability is projected. The FREEDM Super-Cascode costs only one third of the estimated high voltage SiC MOSFETs, and will facilitate early applications of SiC in very high voltage and high frequency power converters.

**4:45PM***A Study of Dynamic High Voltage Output Charge Measurement for 15 kV SiC MOSFET [#1599]*  
Li Wang, Qianlai Zhu, Wensong Yu and Alex.Q Huang   
, FREEDM Systems Center, NC State University, United States

Newly developed 15 kV silicon carbide (SiC) power MOSFETs with fast switching capability enable the reduction of size, weight and complexity of medium voltage power converters. In medium voltage and high frequency applications, zero voltage switching (ZVS) is necessary since significant amount of energy is stored in MOSFETs parasitic output capacitors. Recovering these energy is important for high conversion efficiency while ZVS also reduces the dVdt significantly in these devices. To guarantee complete ZVS, it is crucial to accurately characterize the output charge of devices. In this paper, existing high voltage capacitance and output charge measurement techniques are reviewed. A dynamic half-bridge test method for 15kV SiC MOSFETs output charge measurement is thoroughly analyzed and experimentally verified up to 6 kV. Output capacitance model is then derived using the measured results. The test circuit not only reflects the realistic ZVS scenario, but also achieves high accuracy (less than 1 percent error) without resorting to special equipment or complex configuration which are usually necessary in high voltage test. System level design consideration, error analysis and accuracy certification for this high voltage tester is also given in the paper. Based on the test output charge, derived output capacitance model of 15 kV SiC MOSFETs module is presented.

Distribution-System Utility Interface Topics

Wednesday, September 21, 3:30PM-5:10PM, Room: 102A, Chair: Tsorng-Juu Liang, Deepak Divan

**3:30PM***Unbalanced Voltage Compensation in LV Residential AC Grids [#898]*  
Ionut Trintis, Philip Douglass and Stig Munk-Nielsen   
, Aalborg University, Denmark; Danish Energy Association, Denmark

This paper describes the design and test of a control algorithm for active front-end rectifiers that draw power from a residential AC grid to feed heat pump loads. The control algorithm is able to control the phase to neutral or phase to phase RMS voltages at the point of common coupling. The voltage control was evaluated with either active or reactive independent phase load current control. The control performance in field operation in a residential grid situated in Bornholm, Denmark was investigated for different use cases.

**3:55PM***The Hierarchical Energy Management Control for Residential Energy Harvesting System [#1468]*  
Shuang Zhao, Yuzhi Zhang, Joe Moquin and Alan Mantooth   
, University of Arkansas, United States

A hierarchical energy management system (EMS) for a residential power router is proposed to further reduce costs and stabilize the voltage of a load. There are ten modes of the EMS including three grid-connected modes and seven islanding modes. The state machine diagram shows the transition into and out of these modes. These transitions are based on switching criteria, over generation conditions, and under generation conditions. In comparison to previously published EMS, the proposed EMS could effectively minimize the expense on residential electrical utilities for daily cycling and stabilize the voltage of load when off-grid. The operations of the EMS are based on the local information such as current and voltage without needing the prediction of load and solar illumination. Simulation results reported in this paper verify the functionality of the proposed EMS for the system.

**4:20PM***Reactive Power Distribution Strategy using Power Factor Correction Converters for Smart Home Application [#1246]*  
S M Rakiul Islam, Shawn Maxwell, Md. Kamal Hossain, Sung-Yeul Park and Sungmin Park   
, University of Connecticut, United States; Hongik University, Korea (South)

Multiple unit of PFC converters can be utilized for better power quality in the residential applications. It is important to set proper amount of reactive power contribution from each unit of PFC converter to reduce power loss and increase stability. To set the referenced amount of reactive power contribution for each PFC converter, a dynamic supervisory controller is necessary. In this paper, a wireless based supervisory controller is introduced to mitigate the problem. Multiple unit of unidirectional bridgeless ac-dc boost PFC converters were used as reactive power resources in a smart home application. The supervisory controller is comprised of a discrete Proportional- Integral controller and distributor which sets the reactive power references for each PFC converter. The controller was designed based on the systems identification method. The controller was designed and simulated considering different communication delays. In the ideal condition, the system had no communication delay. However, actual practical system had some reasonable delay. The effect of the use of supervisory controller was observed for dynamic load changing conditions. The simulation was done by using SIMULINK. Reactive power consumption from grid becomes 0VAR within 0.25 second for ideal condition. However, for the actual condition this become 9.35 seconds.

**4:45PM***Active Voltage Balancing Control for Multi HV-IGBTs in Series Connection [#986]*  
Shiqi Ji, Zhengming Zhao, Ting Lu, Fred Wang, Leon Tolbert and Hualong Yu   
, University of Tennessee, United States; Tsinghua University, China

The series connection of insulated gate bipolar transistors (IGBTs) allows the operation at voltage levels higher than the rated voltage of one IGBT. However, the technology has not been widely applied due to transient voltage unbalance. Asynchronous gate drive signals, which cause series-connected IGBTs not to turn-on and turn-off at the same time, result in serious unbalanced voltage sharing. This paper presents an active voltage balancing control for multi series connected HV-IGBTs including the active voltage balancing control (AVBC) circuit integrated in the gate driver and the control for multi series connected IGBTs. The effectiveness of the control has been experimentally validated in a 10 kV dc-link voltage converter using four 4.5 kV HV-IGBTs in series connection.

Thursday, September 22, 8:30AM-10:10AM

Converter Topologies for Wind Power Systems

Thursday, September 22, 8:30AM-10:10AM, Room: 203AB, Chair: Akshay Kumar Rathore, Yilmaz Sozer

**8:30AM***The DOE Next-Generation Drivetrain for Wind Turbine Applications: Gearbox, Generator, and Advanced Si/SiC Hybrid Inverter System [#44]*  
William Erdman and Jonathan Keller   
, Cinch, Inc., United States; National Renewable Energy Laboratory, United States

This paper reports on the design and testing results from the U.S. Department of Energy Next-Generation Wind Turbine Drivetrain Project. The drivetrain design reduces the cost of energy by increasing energy capture through drivetrain efficiency improvements; by reducing operation and maintenance costs through reducing gearbox failures; and by lowering capital costs through weight reduction and a series of mechanical and electronic innovations. The paper provides an overview of the drivetrain gearbox and generator and provides a deeper look into the power converter system. The power converter has a number of innovations including the use of hybrid silicon (Si)/silicon carbide (SiC) isolated baseplate switching modules. Switching energies are compared between SiC and Si PIN diodes. The efficiency improvement by use of the SiC diode in a three-level converter is also described. Finally, a brief discussion covering utility interconnect requirements for turbines is provided with a particular focus on utility events that lead to high transient torque loads on drivetrain mechanical elements.

**8:55AM***Inductorless Boost Rectifier for Small Power Wind Energy Converters [#1606]*  
Carlos Lumbreras, Juan Manuel Guerrero, David Reigosa, Daniel Fernandez and Fernando Briz   
, AST Ingenieria, Spain; University of Oviedo, Spain; Universidad de Oviedo, Spain

This paper analyzes a cost-effective modification of the rectifier plus boost converter power topology which is commonly found in small wind turbine systems. The paper proposes removing the input capacitor after the rectifier and the boost converter inductance. This will be done without adding any LC filter between the permanent magnet generator and the passive rectifier. This paper discusses both the power topology and the control strategy as well as a performance comparison with the usual topology. Simulation and experimental results are presented to demonstrate the technical viability of this proposal.

**9:20AM***High-frequency Isolated DC-DC Converter for Offshore Wind Energy Systems [#1205]*  
Kumar Modepalli, Rohit Suryadevara and Leila Parsa   
, Rensselaer Polytechnic Institute, United States

This paper presents a novel three-phase high-frequency isolated DC-DC converter topology for offshore wind energy systems. The primary side of the converter consists of three half-bridge legs connected to three single-phase star-connected transformers. Each transformer secondary has a full-bridge rectifier and their outputs are connected in series. Constant frequency phase- shift modulation scheme is used for converter control. Leakage inductance of transformers and resonant capacitors, along with the modulation scheme provide zero current switching for converter switches. Modularity, high-gain and high- frequency isolation make the proposed converter a suitable candidate for offshore wind energy conversion systems with high voltage DC transmission. Simulation and experimental results are presented to validate the operation of proposed converter.

**9:45AM***A New Three-phase AC/DC High Power Factor Soft-switched Step-up Converter with High Gain Rectifier Modules for Medium Voltage Grid in Wind Systems [#855]*  
Mehdi Abbasi and John Lam   
, York University, Canada

This paper presents a new single-stage AC/DC step-up soft-switched converter for medium voltage (MV) DC grid for wind energy systems. To achieve close-to-unity power factor, stepping up the voltage and reduce the number of conversion stages, a three-phase boost AC/DC rectifier and a high frequency step-up resonant converter with high gain rectifier modules are combined into a single-stage step-up converter. As a result, the proposed converter is capable to achieve very high voltage gain efficiently without using bulky high turns ratio step-up transformer. Soft switching operation is achieved by using multiple resonant circuit modules. The voltage stress of each power switch is also reduced to half of the DC-link voltage by using a series connection of two strings of switch pairs. In addition, the proposed converter is capable to regulate the output MV grid voltage by utilizing a combination of duty cycle and variable switching frequency control. Results are given on a 1.5MW, 690Vac/40kV system to highlight the merits of the proposed converter.

Energy Storage Systems

Thursday, September 22, 8:30AM-10:10AM, Room: 203C, Chair: Adel Nasiri, Tsai-Fu Wu

**8:30AM***A Comparison of Broadband Impedance Measurement Techniques for Lithium-Ion Batteries [#240]*  
Alfred Waligo and Paul Barendse   
, University of Cape Town, South Africa

Electrochemical impedance spectroscopy (EIS) is a well-known technique that has been employed on various electrochemical cells in order to obtain their impedance spectra.Lithium-ion cells are some of these cells to which it has been applied. The impedance spectra obtained from EIS can be used to estimate various battery state of health (SOH) and state of charge (SOC) characteristics. The lengthy acquisition time associated with standard EIS makes it unsuitable for rapid on-line impedance measurements. Alternative methods that take a shorter time have therefore been proposed. This paper compares the spectra obtained by Harmonic Compensated Synchronous Detection (HCSD) broadband signal technique with EIS and a custom Broadband Impedance Spectroscopy (BIS) technique at different DC bias currents which mimic a real time load. The test cells are industry standard Nickel-Cobalt and Manganese Oxide (NCM) lithium-ion cells. The BIS technique is similar to HSCD in the selection of frequencies however the amplitude of the excitation broadband signal is varied to match the impedance magnitude response of the cell. Also, parameter extraction is performed on both EIS and BIS for fault detection purposes.

**8:55AM***Evaluation of Lithium-ion Battery Second Life Performance and Degradation [#411]*  
Egoitz Martinez-Laserna, Elixabet Sarasketa-Zabala, Daniel-Ioan Stroe, Maciej Swierczynski, Alexander Warnecke, Jean-Marc Timmermans, Shovon Goutam and Pedro Rodriguez   
, Ik4-Ikerlan, Spain; Aalborg University, Denmark; ISEA, RWTH Aachen University, Germany; MOBI research group, Vrije Universiteit Brussel, Belgium; Abengoa Research,Tech. University of Catalonia, Spain

Reusing electric vehicle batteries once they have been retired from the automotive application is stated as one of the possible solutions to reduce electric vehicle costs. Many publications in the literature have analyzed the economic viability of such a solution, and some car manufacturers have recently started running several projects to demonstrate the technical viability of the so-called battery second life. Nevertheless, the performance and degradation of second life batteries remain an unknown topic and one of the biggest gaps in the literature. The present work aims at evaluating the effects of lithium-ion (Li-ion) battery State of Health (SOH) and ageing history over the second life performance on two different applications: a residential demand management application and a power smoothing renewable integration application. The performance and degradation of second life batteries are assessed both at the cell level and at stack level. Homogeneous and heterogeneous stacks are analyzed in order to evaluate the impact of cell-to-cell history and SOH differences over the stack level battery cell performance and degradation behaviour.

**9:20AM***A Distributed ESO based Cooperative Current-Sharing Strategy for Parallel Charging Systems Under Disturbances [#506]*  
Zhou Yanhui, Huang Zhiwu, Liu Weirong, Li Heng and Hongtao Liao   
, Central South University, Changsha, China

In this paper, a distributed extended state observer (ESO) based cooperative control is proposed to achieve current-sharing for parallel chargers under disturbances in energy storage type light rail vehicle systems. By treating the parallel charging system as a nonlinear and non-identical multi-agent system, the current-sharing objective is converted as a distributed leader-follower consensus problem. A distributed ESO is designed to observe total disturbances with the known information from the established mathematical model of subchargers. A tracking differentiator (TD) is established to provide a transitional process for the reference signal to increase the dynamical performance and robustness. Based on ESO and TD, a distributed cooperative control protocol is proposed. Simulation and experimental results are provided to verify the disturbance rejection ability, feasibility and practicability of the proposed distributed current-sharing control method.

**9:45AM***A Comprehensive Study on the Degradation of Lithium-Ion Batteries during Calendar Ageing: The Internal Resistance Increase [#1259]*  
Daniel Stroe, Maciej Swierczynski, Soren Kaer and Remus Teodorescu   
, Aalborg University, Dpt. of Energy Technology, Denmark

Lithium-ion batteries are regarded as the key energy storage technology for both e-mobility and stationary renewable energy storage applications. Nevertheless, the Lithium-ion batteries are complex energy storage devices, which are characterized by a complex degradation behavior, which affects both their capacity and internal resistance. This paper investigates, based on extended laboratory calendar ageing tests, the degradation of the internal resistance of a Lithium-ion battery. The dependence of the internal resistance increase on the temperature and state-of-charge level have been extensive studied and quantified. Based on the obtained laboratory results, an accurate semi-empirical lifetime model, which is able to predict with high accuracy the internal resistance increase of the Lithium-ion battery over a wide temperature range and for all state-of-charge levels was proposed and validated.

Power Quality I

Thursday, September 22, 8:30AM-10:10AM, Room: 101B, Chair: Jonathan Kimball, Dao Zhou

**8:30AM***Enhanced Power Quality and Minimized Peak Current Control in An Inverter based Microgrid under Unbalanced Grid Faults [#138]*  
Wenzhao Liu, Xiaoqiang Guo, Giorgio Sulligoi, Yajuan Guan, Xin Zhao, Baoze Wei, Mehdi Savaghebi and Josep M Guerrero   
, Aalborg University, Denmark; Yanshan University, China; University of Trieste, Italy

The microgrid inverter experiences the power oscillations and current harmonics in case of the unbalanced grid voltage faults. However, there is a trade-off between power oscillations and current harmonics should be considered in three phase three wire inverter systems during the conventional fault ride through control. In order to solve this problem, a novel control strategy is proposed to enhance the output current quality while mitigating the active and reactive output power oscillations. Moreover, a simple current- limited control strategy can be achieved without the necessity of the voltage/current positive/negative sequence extraction. Finally, the simulation tests of the conventional and proposed control solutions are carried out. The results verify the effectiveness of the proposed strategy

**8:55AM***Parallel Interfacing Converters under Unbalanced Voltage: Active Power Oscillation Cancellation with Peak Current Sharing [#166]*  
Farzam Nejabatkhah and Yunwei (Ryan) Li   
, University of Alberta, Canada

Unbalanced voltage has adverse effects on power electronic interfacing converters (IFCs) operation such as output power oscillations, DC link voltage oscillations and peak current increase. These adverse effects can be aggregated in parallel IFCs with common DC and AC link, which are commonly used to connect AC and DC subsystems in hybrid AC/DC microgrid or to interface high-power distributed generations/storage elements to AC subsystem. In this paper, two novel control strategies for parallel IFCs operation under unbalanced voltage are proposed, which are focusing on active power oscillation cancellation and sharing of collective peak current of parallel IFCs among IFCs considering their power ratings. In the first proposed control strategy, IFCs power coefficient factors are controlled for cancellation of active power oscillation and collective peak current sharing of parallel IFCs. In the second proposed control strategy, IFCs peak currents are controlled for controlling targets. In this paper, individual and parallel IFCs peak currents are thoroughly studied, and their relationship with active power oscillation cancellation are analyzed. Based on analysis, it is proven that collective peak current of parallel IFCs is constant under zero active power oscillation in the fixed average active powers output. Both proposed control strategies ensure the peak currents of individual IFCs to be approximately in-phase with collective peak current of parallel IFCs, which provide minimum peak currents summation of IFCs.

**9:20AM***The Reverse Zero-Sequence Current Compensation Strategy for Back-to-Back Active Power Conditioners [#205]*  
Tung Yueh, Terng-Wei Tsai, Yaow-Ming Chen, Yih-Der Lee and Yung-Ruei Chang   
, National Taiwan University, Taiwan; Institute of Nuclear Energy Research, Taiwan

In this paper, a novel reverse zero-sequence current (RZSC) compensation strategy for three-phase four-wire back-to-back active power conditioner (APC) is proposed. The objective of the APC is to achieve the active and reactive power compensation between two micro-grids. However, for the unbalanced voltage sag micro-grid system, the double- line frequency oscillation exists in the output active/reactive power of the APC. In order to eliminate these power oscillation, the zero-sequence current control must be utilized, but it will produce the line frequency ripple voltage on the split capacitors of the dc-bus. The capacitor ripple voltage will speed up the aging process and reduce its life-time. Therefore, the RZSC strategy is proposed to compensate the impact of the ripple voltage to the split capacitors. The circuit configuration and control block diagram of the APC will be introduced. The operation principle of the proposed RZSC strategy will be presented. Both computer simulations and hardware experimental results are presented to verify the performance of the proposed RZSC.

**9:45AM***Harmonic Mitigation in Interphase Power Controllers Using Passive Filter-Based Phase Shifting Transformer [#108]*  
Mohammad Amin Chitsazan and Andrzej M Trzynadlowski   
, University Of Nevada, Reno, United States

A novel, genetic-algorithm based, design method of the passive filter-based phase shifting transformers is presented. The method improves the reliability, effectiveness, and accuracy of the filter. The filter is employed in an interphase power controller (IPC), a FACTS device unique in its power- transmitting properties. The paper demonstrates how the implementation of the proposed filter in the IPC structure significantly reduces the total harmonic distortion without affecting the IPC characteristics.

AC Microgrids I: Modelling and Stability

Thursday, September 22, 8:30AM-10:10AM, Room: 203DE, Chair: Adel Nasiri, Reza Ahmadi

**8:30AM***Modeling and Stability Analysis of the Small-AC-Signal Droop Based Secondary Control for Islanded Microgrids [#1412]*  
Teng Wu, Zeng Liu, Jinjun Liu, Baojin Liu and Shike Wang   
, Xian Jiaotong University, China

The recently proposed small-AC-signal droop based secondary control is very attractive for microgrids to restore the voltage and frequency of overall system and to share the output power between paralleled distributed generations (DGs). However, the previous work has not discussed the system stability of the novel secondary control method. This paper presents a small-signal model for the microgrids regulated by the novel secondary control method. Then the system stability is analyzed by accessing the eigenvalues of the proposed model. Finally, the correctness of theoretical analysis is verified by both simulation and experimental results.

**8:55AM***A Small-AC-Signal Injection Based Harmonic Power Sharing Method for Islanded Microgrids [#61]*  
Baojin Liu, Zeng Liu, Jinjun Liu, Teng Wu, Shike Wang and Xin Meng   
, Xi'an Jiaotong University, China

This paper proposes a novel control method for harmonic power sharing in an islanded microgrid, without employing any control interconnections between the distributed generation (DG) units. The fundamental real and reactive power is shared by implementing conventional P-f and Q-V droop control. A virtual negative output impedance at harmonic frequency is introduced to control the distribution of harmonic power. Moreover, a small-AC-signal is injected in each DG unit for dynamically regulating the magnitude of its virtual negative harmonic output impedance to realize evenly sharing of harmonic power among all DG units according to their available harmonic power capacities. This novel method can also provide improved load voltage quality and does not need information about line impedance. Simulation results on PSCAD are offered to validate the proposed method.

**9:20AM***Improvement of Transient Stability in Inverter-Based AC Microgrid via Adaptive Virtual Inertia [#520]*  
XiaoChao Hou, Hua Han, Chaolu Zhong, Wenbin Yuan, Meijie Yi and Ying Chen   
, Central South University, China; Central South Universiy, China

Unlike centralized synchronous generator (SG) in conventional power system, distributed microsources are parallel connected to neighbors by inverters, which are less inertia. To improve the transient stability, inverter based distributed generators (DG) can draw an analogy between the storage and rotor rotational kinetic energy of SG in inertia function. Instead of emulating a fixed virtual inertia, this study proposes adaptive virtual inertia to alleviate the frequency response. In the transient process, a large inertia is implemented when the frequency will deviate from the normal value, and a low inertia is adopted when it is necessary to recover the frequency. The proposed method can enhance the anti interference and overload capacity, so that frequency stability is strengthened. Lyapunov stability analysis is utilized to prove the convergence. Simulation results are presented to verify the effectiveness of the method.

**9:45AM***Frequency Support Properties of the Synchronous Power Control for Grid-Connected Converters [#1109]*  
Weiyi Zhang, Daniel Remon, Joan Rocabert, J. Ignacio Candela, Alvaro Luna and Pedro Rodriguez   
, Technical University of Catalonia, Spain; Abengoa, Spain

Grid-connected converters with primary frequency control and inertia emulation have emerged and are promising for future renewable generation plants because of the contribution in power system stabilization. This paper gives a synchronous active power control solution for grid-connected converters. As design considerations, the virtual angle stability and transient response are both analyzed, and the detailed implementation structure is also given without entailing any difficulty in practice. The analysis and validation of frequency support characteristics are particularly addressed. The 10 kW simulation and experimental frequency sweep tests on a regenerative source test bed present good performance of the proposed control in terms of showing inertia and droop characteristics, and the controllable transient response is also demonstrated.

Battery Management for Transportation Electrification I

Thursday, September 22, 8:30AM-10:10AM, Room: 102D, Chair: Yilmaz Sozer, Berker Bilgin

**8:30AM***A Pack-to-Cell-to-Pack Battery Equalizer with Soft-Switching Based on Buck-Boost and Bidirectional LC Resonant Converters [#680]*  
Zeyuan Li, Yunlong Shang, Bin Duan and Chenghui Zhang   
, Shandong University, China

A pack-to-cell-to-pack battery equalizer with soft-switching based on buck-boost converter and bidirectional LC resonant converter is proposed to achieve a fast and high-efficiency battery equalization. The buck-boost converter is employed to transmit energy from a high tension supply to a low one in the buck mode or from a low one to a high one in the boost mode with zero-voltage switching (ZVS). The bidirectional LC resonant converter is employed to automatically transfer energy with zero-current switching (ZCS) with electrical isolation. A prototype with four lithium-ion battery cells is implemented. Experimental results show the proposed scheme exhibits outstanding balancing performance, and the measured peak conversion efficiency is about 93% in the cell-to-pack mode and 72.5% in the pack-to-cell mode.

**8:55AM***A New Perspective on Battery Cell Balancing: Thermal Balancing and Relative Temperature Control [#689]*  
Ye Li and Yehui Han   
, University of Wisconsin-Madison, United States

This paper introduces a new perspective on cell balancing (equalization) in a lithium-ion battery pack by proposing the thermal balancing concept of battery cells. Thermal balancing can be achieved by relative temperature control based on either conventional active cell balancing circuits or module-integrated systems. Compared to voltage/state-of-charge (SoC) balancing, relative temperature can be used as the balancing target with several advantages. First, absolute temperature directly affects the lifetime and usable capacity of battery cell. Second, the relative temperature between cells degrades the uniformity of the cells and increase the imbalance in various parameters. Third, temperature usually has a slow dynamic which makes it an ideal control target for low balancing power compared to the high charging/discharging power. Last, thermal balancing control can take over the job of the thermal management system to a certain degree. Therefore the balancing function could be potentially built into the thermal management system. In this paper, two algorithms are developed to achieve thermal balancing: direct relative temperature control and virtual heat sink temperature control. A simple battery system thermal model is developed and the proposed control algorithms are validated.

**9:20AM***Advanced Cell-level Control for Extending Electric Vehicle Battery Pack Lifetime [#1451]*  
Muhammad Muneeb Ur Rehman, Fan Zhang, Michael Evzelman, Regan Zane, Kandler Smith and Dragan Maksimovic   
, Utah State University, United States; University of Colorado, United States; National Renewable Energy Laboratory, United States

A cell-level control approach for electric vehicle battery packs is presented that enhances traditional battery balancing goals to not only provide cell balancing but also achieve significant pack lifetime extension. These goals are achieved by applying a new life-prognostic based control algorithm that biases individual cells differently based on their state of charge, capacity and internal resistance. The proposed life control approach reduces growth in capacity mismatch typically seen in large battery packs over life while optimizing usable energy of the pack. The result is a longer lifetime of the overall pack and a more homogeneous distribution of cell capacities at the end of the first life for vehicle applications. Active cell balancing circuits and associated algorithms are used to accomplish the cell-level life extension objectives. This paper presents details of the cell-level control approach, selection and design of the active balancing system, and low-complexity state-of-charge, capacity, and series resistance estimation algorithms. A laboratory prototype is used to demonstrate the proposed control approach. The prototype consists of twenty-one 25 Ah Panasonic lithium-Ion NMC battery cells from a commercial electric vehicle and an integrated BMS/DC-DC system that provides 750 W to the vehicle low voltage auxiliary loads.

**9:45AM***A Battery Cell Balancing Control Scheme with Minimum Charge Transfer [#296]*  
Zhiyuan Shen, Handong Gui and Leon Tolbert   
, Silergy Corp., China; The University of Tennessee, Knoxville, United States

According to the analysis of the imbalance in series-connected lithium-ion batteries, the state-of-health (SOH) and the energy utilization is mainly influenced when the cells are fully charged or discharged. Therefore, balancing is not necessarily required all the time. In addition, the energy loss of the balancing system is closely related to the charge transfer among different cells. This paper proposes an active balancing control scheme that utilizes the required charge of each cell as the balancing reference. With the scheme, the charge transfer during the balancing process can be minimized so that the energy loss can be reduced and the balance can be achieved when the cells are fully charged or discharged, which not only improves the battery lifetime but also increases the available energy. The proposed control is applied in a balancing system based on the direct cell-to-cell architecture and bi-directional buck/boost converter. Experimental results have verified the effectiveness of the proposed control.

Grid Connected Single-Phase Inverters

Thursday, September 22, 8:30AM-10:10AM, Room: 202A, Chair: Mahshid Amirabadi, Fernando Briz

**8:30AM***Double Line Frequency Ripple Cancelling for Single-Phase Quasi-Z-Source Inverter [#842]*  
Yuan Li, Wenqiang Gao, Jiayi Li, Rui Zhang and Fan Fang   
, Sichuan University, China

Double line frequency ripple power inherently exists in single phase dc-ac or ac-dc pulse width modulation converters because of instantaneous power unbalance between the dc and ac side. In order to achieve stable operation and maintain a high maximum power point tracking (MPPT) efficiency, traditional single-phase quasi-Z-source inverter (QZSI) for photovoltaic application uses large electrolytic dc capacitors in the impedance network to suppress this double line frequency ripple. This paper proposed an active power decoupling method to cancel the ripple in both the input and impedance network. By adding another phase leg, an ac capacitor and a high frequency inductor in series, the second ac power path is developed to absorb the power pulsating at twice the line frequency. With selected capacitance and closed- loop control for the voltage on the added ac capacitor, the ripple would be eliminated with the minimum costs. The other ac output of the QZSI would not be influenced because the original two phase legs (the original H-bridge) maintains the same operation. The merits of the presented method includes 1) reduced device size by replacing bulky dc capacitor to small ac capacitor; 2) ripple free input to achieve high MPPT efficiency. Theoretical analysis, control strategy, simulation and experimental results are provided to demonstrate and verify the method.

**8:55AM***Hybrid control scheme for the current loop of a grid connected inverter operating with highly distorted grid voltage [#992]*  
Julio Cesar Viola, Jose Restrepo, Jose Manuel Aller and Flavio Quizhpi   
, Universidad Politecnica Salesiana/Prometeo Proj., Ecuador; Universidad Simon Bolivar, Venezuela; Universidad Simon Bolivar/Prometeo Project, Venezuela; Universidad Politecnica Salesiana, Ecuador

The complete design of the current control loop for single-phase inverters connected to weak grids is presented. The problems associated to the design of current control loop when highly distorted grid voltages are present and LCL filters are used to couple the inverters to the grid, are analyzed. Fourier coefficients decomposition is used to obtain an ahead-of-time version for the nonideal voltage signal which allows the compensation of the current control loop delay. Also the relevance of nonideal characteristic of the inverter as the deadtime effect on the shape of the controlled current is analyzed and compensated. Simulations and experimental results are included for the proposed methods.

**9:20AM***Single-Phase LLCL-Filter-based Grid-Tied Inverter with Low-Pass Filter Based Capacitor Current Feedback Active damper [#1343]*  
Liu Yuan, Wu Weimin, He Yuanbin, Chung Shu-Hung and Blaabjerg Frede   
, Shanghai Maritime Univ., China; City Univ. of Hong Kong, Hong Kong; Aalborg Univ., Denmark

The capacitor-current-feedback active damping method is attractive for high- order-filter-based high power grid-tied inverter when the grid impedance varies within a wide range. In order to improve the system control bandwidth and attenuate the high order grid background harmonics by using the quasi-PR control method, the digital delay is preferred to be reduced as much as possible. However, when the time between the sampling point and the updating point is reduced, the disturbance caused by the switching noises will be easily introduced into the sampling signals, resulting in possible disability. In this paper, a low pass filter is proposed to be inserted in the capacitor current feedback loop of LLCL-filter based grid-tied inverter together with a digital proportional and differential compensator. The detailed theoretical analysis is given. For verification, simulations on a 2kW/220V/10kHz LLCL-filter-based grid- tied inverter have been presented.

**9:45AM***A single-phase tri-state integrated Buck-Boost inverter suitable to operate in grid-connected and island modes [#1076]*  
Jose Carlos Pena, Cindy Paola Guzman and Carlos Alberto Canesin   
, Universidade Estadual Paulista, Peru; Universidade Estadual Paulista, Colombia; Universidade Estadual Paulista, Brazil

This paper introduces a methodology to model and control a single-phase tri state integrated Buck-Boost inverter suitable for low power distributed generation with the capability to operate in grid connected and island modes. The tri-state modulation is adopted in order to achieve power decoupling by means of average inductor current. This way it is possible to control the DC/AC conversion independently of the input current. The proposed strategy considers a multiple loop control scheme, where controllers are tuned based on a linearized models of the system. Main experimental results from a 300W prototype are included and discussed.

Modular Multilevel Converters (MMC) I

Thursday, September 22, 8:30AM-10:10AM, Room: 202B, Chair: Jiangchao Qin, Wim van der Merwe

**8:30AM***DC Fault Ride Through of Multilevel Converters [#1019]*  
Geraint Chaffey, Paul Judge, Michael Merlin, Philip Clemow and Tim Green   
, Imperial College London, United Kingdom

Modular Multilevel Converters (MMC) can provide significant advantages for power transmission applications, however there are remaining challenges trading off DC fault response, losses and controllability. Alternative multilevel converter topologies using combinations of full bridge and half bridge submodules or series switches allow for competitive efficiency whilst retaining control over the DC fault current. Several possible converter fault responses are analysed to evaluate appropriate converter control actions. Experimental results from a 60 submodule 15 kW demonstrator are presented to validate the DC fault performance of the full bridge MMC, the mixed stack MMC and the alternate arm converter. It is shown that each can control the current into a low impedance DC fault, and there no requirement to block the semiconductor devices.

**8:55AM***Reverse Blocking Sub-Module Based Modular Multilevel Converter with DC Fault Ride-Through Capability [#118]*  
Xiaofeng Yang, Yao Xue, Bowei Chen, Zhiqin Lin, Yajie Mu, Trillion Q. Zheng and Seiki Igarshi   
, Beijing Jiaotong University, China; Fuji Electric Co., Ltd., Japan

Modular multilevel converter (MMC) is one of the promising voltage source converter topologies in the field of high voltage direct current (HVDC) transmission system. Based on analysis of the existing sub-module topologies, an improved half-bridge sub-module topology based on reverse blocking IGBTs (RB-HBSM) was proposed for solving the fault ride through issues. In this paper, the fault current blocking mechanism and the electrical stress of the main power switches are studied firstly in detail. Then the fault control flow chart is presented. Feasibility of the proposed sub-module topology and the fault protection theory are verified by simulation. The proposed RB-HBSM-MMC topology is able to block the fault current without changing the original control and modulation strategies compared with the conventional MMC, thus it further reduces the complicity of industry design.

**9:20AM***Closed-loop Control of the DC-DC Modular Multilevel Converter [#671]*  
Heng Yang and Maryam Saeedifard   
, Georgia Institute of Technology, United States

The DC-DC Modular Multilevel Converter (MMC), which has originated from the AC- DC MMC circuit topology, is an attractive converter topology for interconnection of medium-/high-voltage DC grids. Proper operation of the DC-DC MMC necessitates injection of an AC circulating current to maintain its submodule (SM) capacitor voltages balanced. The AC circulating current, however, needs to be minimized for efficiency improvement. In addition, a unique type of imbalance amongst the SM capacitor voltages that is caused by DC power flow needs to be mitigated. This paper proposes a closed-loop control strategy for the DC-DC MMC to simultaneously regulate the DC-link currents, maintain the SM capacitor voltages balanced and minimize the AC circulating current. Performance and effectiveness of the proposed control strategy are evaluated based on simulation studies in the Matlab Simulink and experimentally verified on a laboratory prototype.

**9:45AM***New MMC Capacitor Voltage Balancing using Sorting-less Strategy in Nearest Level Control [#996]*  
Mattia Ricco, Laszlo Mathe and Remus Teodorescu   
, Aalborg University, Denmark

This paper proposes a new strategy for balancing the Capacitor Voltages (CVs) for Modular Multilevel Converters (MMCs). The balancing is one of the main challenges in MMC applications and it is usually solved by adopting a global arm control approach. For performing such an approach, a sorted list of the SubModules (SMs) according to their capacitor voltages is required. A common way to accomplish this task is to implement a sorting algorithm in the same controller used for the modulation technique. However, the execution time and the computational efforts of these kinds of algorithms increase very rapidly when the number of SMs grows. A novel idea is presented in this paper by using a mapping strategy that directly stores in a ranked list the SMs according to the measured CVs. Avoiding the use of sorting algorithms leads to a considerable reduction of the execution time as well as the computational efforts.

DC-DC Isolated: LLC

Thursday, September 22, 8:30AM-10:10AM, Room: 102C, Chair: Jason Stauth, Vladimir Blasko

**8:30AM***A New Tightly Regulated Dual Output LLC Resonant Converter with PFM plus Phase-shift Control [#216]*  
Xun Gao, Hongfei Wu, Yan Xing, Haibing Hu and Yu Zhang   
, Nanjing Univ. of Aeronautics and Astronautics, China; Shanghai Institute of Space Power-sources, China

A new dual-output LLC resonant converter is presented for high power density and high efficiency dual-output application. A new control freedom is provided by replacing two diodes in the secondary-side rectifier with two MOSFETs. Variable frequency modulation plus secondary side phase-shift modulation scheme is adopted to realize precise regulation of both the two outputs simultaneously. Meanwhile, zero-voltage switching and zero-current switching can be ensured for all the MOSFETs and diodes, respectively, to reduce switching losses. The operational principles, characteristics, control strategies, and design considerations are analyzed in detail. Experimental results with a 420W-rated dual-output prototype are provided to verify the effectiveness and advantages of the presented converter.

**8:55AM***Analytical Model for LLC Resonant Converter With Variable Duty-Cycle Control [#779]*  
Yanfeng Shen, Huai Wang, Frede Blaabjerg, Xiaofeng Sun and Xiaohua Li   
, Aalborg University, Denmark; Yanshan University, China

In LLC resonant converters, the variable duty-cycle control is usually combined with a variable frequency control to widen the gain range, improve the light-load efficiency, or suppress the inrush current during start-up. However, a proper analytical model for the variable duty-cycle controlled LLC converter is still not available due to the complexity of operation modes and the nonlinearity of steady-state equations. This paper makes the efforts to develop an analytical model for the LLC converter with variable duty-cycle control. All possible operation models and critical operation characteristics are identified and discussed. The proposed model enables a better understanding of the operation characteristics and fast parameter design of the LLC converter, which otherwise cannot be achieved by the existing simulation based methods and numerical models. The results obtained from the proposed model are in well agreement with the simulations and the experimental verifications from a 500-W prototype.

**9:20AM***Three-Phase LLC Resonant Converter with Integrated Magnetics [#1473]*  
Wilmar Martinez, Noah Mostafa, Yuki Itoh, Masayoshi Yamamoto, Jun Imaoka, Kazuhiro Umetani, Kimura Shota, Nanamori Kimihiro and Endo Shun   
, Shimane University, Japan; Kyushu University, Japan; Okayama University, Japan

Recently, Electric Vehicles (EVs) have required high power density and high efficiency systems in order to save energy and costs. Specifically, in the DC-DC converter that feeds the non-propulsive loads in these vehicles, where the output voltage is much lower than the one of the energy storage unit. Therefore, the output current becomes quite high, and the efficiency and power density are reduced due to the high current ratings. Furthermore, magnetic components usually are the biggest contributors to the mass and volume in these converters. This paper proposes a Three-phase LLC resonant converter with one integrated transformer where all the windings of the three independent transformers are installed into only one core. Using this technique, a high reduction in the core size and thereby an increment in the power density and a reduction of the production cost are obtained. In addition, this integrated transformer is intended to be applied in the novel Three-phase LLC resonant converter with Star connection that is expected to offer reduction of the imbalanced output current, which is produced by tolerances between the phase components. Finally, the proposed converter with the novel integrated transformer is discussed and evaluated from the experimental point of view. As a result, a 70% reduction in the mass of the magnetic cores was achieved.

**9:45AM***Accurate ZVS Boundary in High Switching Frequency LLC Converter [#1546]*  
Ren Ren, Liu Bo, Jones Edward Andrew, Wang Fred, Costinett Daniel Jes and Zhang Zheyu   
, the University of Tennessee, United States

Due to the realization of zero voltage switching (ZVS) under the full load range, LLC resonant converter is widely adopted in the telecom, battery charger and several applications, characterized with high efficiency, high frequency and high power density, to realize DC conversion. Recently, by using Gallium Nitride (GaN) HFETS, switching frequency of LLC converters is further increased. However, ZVS failure cannot be predicted accurately in the high switching frequency condition by only considering traditional constraints generally applied in the low frequency design. The traditional constraints result in a too optimistic estimation of the dead time to obtain ZVS without considering the reverse resonance under the dead time and the design of resonant parameters at high resonant frequency and high load condition. The experiment shows the LLC converter loses ZVS even through the converter satisfies the ZVS constraints proposed by previous paper. In this paper, the failure mode will be investigated in detail and an accurate ZVS boundary is proposed for high frequency LLC converter design. The proposed theory was verified on a 1 MHz, 1500 W LLC prototype.

Modeling and Control of Grid Connected Converter I

Thursday, September 22, 8:30AM-10:10AM, Room: 202D, Chair: Sung Yeul Park, Fernando Briz

**8:30AM***A Unified Control of Back-to-Back Converter [#481]*  
Alberto Rodriguez-Cabero, Francisco Huerta Sanchez and Milan Prodanovic   
, IMDEA Energy Institute, Spain

In this paper a novel unified modelling and control procedure for Back-to- Back converters is introduced. The proposed procedure captures in a single state-space model detailed converter dynamics of both LCL filters and DC- capacitor. A linear multivariable approach has been identified as the most suitable control strategy for taking full advantage of the unified model. A state-feedback controller has been designed for controlling both inverter output currents and DC-bus voltage. It has been shown the main advantage of the proposed modelling procedure is in its detailed knowledge of the existing coupling between the AC currents and the DC-capacitor voltage. As a result, the proposed unified controller takes into account the whole system dynamics in order to maintain the DC-bus voltage nearly constant. The proposed control strategy was experimentally validated by using two 15kVA VSCs (Voltage Sourced Converters) in Back-to-Back configuration. The performance of the unified controller was compared with the performance of the conventional strategy based on the cascade control structure. It was experimentally demonstrated the proposed unified control significantly outperforms the conventional control of DC-bus voltage.

**8:55AM***Control of an Islanded Power-Electronic Converter as an Oscillator [#688]*  
Ricardo Perez, Cesar Silva and Amirnaser Yazdani   
, Universidad Tecnica Federico Santa Maria, Chile; Ryerson Universiy, Canada

This paper proposes the use of the feedback-linearization control technique for the regulation of the voltage amplitude and frequency of power-electronic converters. This control strategy linearize the trajectory of a nonlinear system between any two equilibrium points, and thus allowing to use linear control technique. The reference tracking robustness of the proposed control technique is assessed under linear and nonlinear loads, in addition to bidirectional power flow, through simulations.

**9:20AM***Power control for Grid-connected Converter to Comply with Safety Operation Limits during Grid Faults [#932]*  
Shida Gu, Xiong Du, Ying Shi, Yue Wu, Pengju Sun and Heng-Ming Tai   
, Chongqing University, China; University of Tulsa, United States

This paper presents a new power control strategy of grid-connected converter under grid fault conditions. Positive- and negative-sequence reactive power are controlled separately in order to effectively support unbalanced grid voltage. Both maximum phase current limit and maximum active power oscillation limit are taken into consideration which makes the converter operate safely under grid faults. Spare capacity are fully used to generate active power. Reactive power is generated immediately and active power is generate gradually during calculation procedure which makes it possible for online application. Also, generating active power gradually lighten the burden of crowbar or other energy transfer devices and bring less impacts to grid. Experiment results prove that the proposed method is effective.

**9:45AM***An online measurement method for common-mode impedance in three-phase grid-connected converters [#557]*  
Tuomas Messo, Tomi Roinila, Jukka Viinamaki and Teuvo Suntio   
, Tampere University of Technology, Finland

A typical three-phase two-level converter produces high frequency common-mode voltage when sinusoidal PWM is used. Common-mode currents are produced which depend on the magnitude of common-mode impedance seen by the inverter. This paper proposes a method to measure the common-mode impedance seen by the inverter online by utilizing a SiC-inverter.

Fault Prognosis for Power Devices

Thursday, September 22, 8:30AM-10:10AM, Room: 102E, Chair: Marco Liserre, Juan Rivas-Davila

**8:30AM***Remaining Useful Lifetime Estimation For Thermally Aged Power Mosfets With Ransac Denoising Algorithm [#1442]*  
Serkan Dusmez, Mehrdad Heydarzadeh, Mehrdad Nourani and Bilal Akin   
, University of Texas at Dallas, United States

This paper focuses on the remaining useful lifetime (RUL) estimation of power MOSFETs, which are stressed by thermal cycling. The relative change in on-state resistance is identified as the aging precursor for die attach solder degradation after exhaustive experiments. A data-driven RUL estimation algorithm based on a linear approximation model is proposed. The empirical coefficients are estimated by the classical least squares method. However, the initial part of the data contains a significant number of outliers, which decreases the estimation accuracy. In order to remove the outlier effect and make the estimation robust, least-squares method is applied to only inliers that are determined by random sample consensus (RANSAC) algorithm. With the exclusion of outliers, the RUL estimation is improved for the ones that contain outliers. The accuracy of the proposed RUL estimation tool is verified on a number of thermally aged discrete power MOSFET data

**8:55AM***An Analytical Model for False Turn-On Evaluation of GaN Transistor in Bridge-Leg Configuration [#566]*  
Ruiliang Xie, Hanxing Wang, Gaofei Tang, Xu Yang and Kevin. J Chen   
, Hong Kong University of Science and Technology, Hong Kong; Xi'an Jiaotong University, China

Gallium Nitride (GaN) transistors are especially attractive in their capability of switching at high frequencies, and enable power conversion systems with reduced size and higher efficiency. However, owing to the low threshold voltage of the commercially available enhancement-mode (E-mode) GaN devices, the devices are more prone to false turn-on phenomenon, leading to larger switching losses, circuit oscillation and even shoot-through in bridge-leg configuration. In order to enlarge the gate terminal's safe operating margin without increasing the reverse conduction loss during dead-time, a negative gate voltage bias for turn- off and an anti-parallel diode can be applied to GaN transistor. In this work, to accurately evaluate the detailed turn-on characteristics of GaN transistors in bridge-leg configuration,analytical device models that count for the strong nonlinearities of device's I-V and C-V characteristics are firstly developed. Then an analytical circuit model taking into account the circuit parameters as well as the intrinsic behaviors of GaN transistor and anti-parallel diode is established. Thus, the critical transient waveforms, such as displacement currents and false triggering voltage pulse on gate terminal can be simulated. The proposed models are then verified on a testing board with GaN-based bridge- leg circuit. To provide design guidelines for suppressing false turn-on, impacts of circuit parameters are investigated based on the proposed model.

**9:20AM***Advanced Condition Monitoring System Based on On-Line Semiconductor Loss Measurements [#1105]*  
Tobias Krone, Lan Dang Hung, Marco Jung and Axel Mertens   
, Leibniz Universitaet Hannover, Germany; Fraunhofer IWES, Germany

This paper presents an FPGA-based on-line condition monitoring system integrated at gate-driver voltage level. The system uses the change of on-state voltage and thermal resistance as ageing indicators. The monitoring is realized by implementing an on-line semiconductor power loss measurement system for switching and on-state losses and a thermal model of the module. Apart from the concept, its practical implementation is described, and the experimental results are given.

**9:45AM***A Comprehensive Study on Variations of Discrete IGBT Characteristics Due to Package Degradation Triggered by Thermal Stress [#620]*  
Syed Huzaif Ali, Serkan Dusmez and Bilal Akin   
, University of Texas at Dallas, United States

Identification of power device failure precursors is essential for condition monitoring, fault severity assessment and lifetime estimation. These tools constitute the fundamental elements to achieve highly reliable power converters with self-diagnosis capability, which can report incipient faults at very early stage. In this paper, several discrete IGBTs are thermally aged on a custom-built modular test-bed. I-V characteristics are monitored periodically using an automated curve tracer throughout the aging, and the fault/aging related patterns are comprehensively analyzed. The variations in saturation voltage, gate threshold voltage, transfer capacitances, and gate charge, which are the potential candidates for aging precursors, are analyzed in detail. The experimental and failure analysis results suggest that on-state voltage drop and gate threshold voltage are the two essential aging precursors for monitoring die- attach solder and gate oxide degradations.

Thermal Analyses of Electric Machines

Thursday, September 22, 8:30AM-10:10AM, Room: 102B, Chair: Bulent Sarlioglu, Patel Bhageerath Reddy

**8:30AM***Experimental Calibration in Thermal Analysis of PM Electrical Machines [#644]*  
Sabrina Ayat, Rafal Wrobel, James Goss and David Drury   
, University of Bristol, Motor Design Ltd, United Kingdom; Motor Design Ltd, United Kingdom; University of Bristol, United Kingdom

Thermal design of electric machines frequently involves tests on a fully constructed prototype to calibrate various build factors associated with the manufacture, assembly and materials used in the hardware construction. The prototype machine is usually instrumented with multiple temperature sensors providing a detailed insight into the temperature distribution. The resolution of the experimentally gathered data is usually limited by the number of temperature sensors, and therefore the quality of model calibration is highly affected by the input data. This paper investigates the issue of thermal model calibration in the context of available machine hardware and measured data resolution. Also, the research evaluates the most suitable thermocouple location with reference to the model complexity, from reduced-order lumped-parameters circuit to high-fidelity finite element method (FEM). The investigation is focused on the stator-winding assembly, which is frequently associated with the main source of power loss within a PM machine body. A prototype of a PM generator has been selected to illustrate the effects associated with the model calibration. Tests on a representative stator-winding sub-assembly (motorette) have been used in the analysis. The results suggest that the measured data from alternative sensor locations for a given machine region has a significant impact on the quality of the model calibration and consequently temperature predictions.

**8:55AM***Thermal Conductivity Evaluation of Fractional-Slot Concentrated-Winding Machines [#11]*  
Aldo Boglietti, Silvio Vaschetto, Marco Cossale and Thiago Dutra   
, Politecnico di Torino, Italy; University of Santa Caterina, Brazil

The use of Fractional-Slot Concentrated Windings (FSCW) in electrical machines allows more compact, efficient and reliable design with respect to machines equipped with distributed windings. However, an electromagnetic design linked to a thermal analysis of the electrical machine is mandatory to achieve the desired performance and to fulfill the requirements of efficiency and reliability. One of the most critical issues in thermal design of electrical machines is to assign fair values for the input parameters of the thermal simulation models, particularly those related to the stator winding insulation system. This paper deals with the assessment of the equivalent thermal conductivity of the insulation system of FSCW machines. For this purpose, three FSCW electrical machines for different applications were evaluated via an experimental method based on a dc thermal transient test. Whereas the investigated machines present different characteristics among themselves, different approaches were required to properly estimate the thermal conductivity.

**9:20AM***Thermal Performance Modeling of Foil Wound Concentrated Coils in Electric Machines [#1449]*  
Michael Rios, Giri Venkataramanan, Annette Muetze and Heinrich Eickhoff   
, University of Wisconsin - Madison, United States; Graz University of Technology, Austria

While the use of foil windings in transformers and air core inductors is not uncommon, their use in electric machines is just emerging. Although prototype realizations have been reported in the literature, a definitive analysis of their thermal performance is necessary to evaluate their potential for broad applications. This paper is devoted to presenting a comprehensive model for evaluating their thermal performance including loss modeling and temperature rise prediction in realistic designs. An overview of foil windings in electric machines and their advantages in improved fill factor is presented, along with experimental results that compare the AC losses and temperature distribution under identical steady-state operating conditions with a prototype round conductor coil and foil conductor coil. A lumped parameter thermal model that predicts the heat transfer behavior of the foil conductor coil is presented along with supporting experimental results.

**9:45AM***Experimental Validation in Operative Conditions of Winding Thermal Model for Short-Time Transient [#17]*  
Aldo Boglietti, Silvio Vaschetto, Marco Cossale and Thiago Dutra   
, Politecnico di Torino, Italy; University of Santa Caterina, Brazil

This paper presents the validation of a first-order winding thermal model in machine operative conditions. The proposed model can be used in motor control strategies for the winding temperature prediction during transient overload or vice versa, for the prediction of the maximum time duration of the overload maintaining the winding temperature within the limit imposed by the class of insulation. The thermal model has been validated using two different electrical machines. The first one is a 10 kW automotive starter- generator prototype for mini-hybrid powertrain equipped with distributed bar windings, while the second one is a 2.2 kW total enclosed fan cooled industrial induction motor equipped with conventional stranded wire windings. To both machines it is mainly required a short-duty transient operation in overload conditions. In particular, the automotive starter-generator must accomplish the engine cranking and torque assistance during the vehicle acceleration and braking, while the considered industrial induction machine has to operate in intermittent service in overload conditions for machine tool applications. As a consequence, an accurate stator winding temperature prediction is mandatory to fully exploit the machine performance. For both motors, the thermal model parameters have been evaluated by fast experimental approach and subsequently, the model has been validated during operative overload conditions.

Transverse Flux Machines

Thursday, September 22, 8:30AM-10:10AM, Room: 101A, Chair: Keith Corzine, Daniel Ludois

**8:30AM***A Hybrid-Excited Axial Transverse Flux Permanent Magnet Machine [#1311]*  
Emrullah Aydin, Ju Hyung Kim, Emin Yildiriz, Mehmet Timur Aydemir and Bulent Sarlioglu   
, Electrical-Electronic Engineering, Gazi Univ., Turkey; Electrical and Computer Engineering, UW-Madison, United States; Electrical-Electronic Engineering, Duzce Univ., Turkey

This paper proposes a modular hybrid-excited axial transverse flux permanent magnet machine. The operational principles and performance characterization are presented. The toroidal excitation windings are placed on both teeth of the U-type core and are excited by a field current. The field current can either buck or boost the magnetic flux produced by the circular permanent magnets on the rotor disk. The finite element analysis is performed to quantify the change in flux linkage, back-EMF, and output power as a function of field current. This research contributes to the field weakening or intensifying feature of the axial transverse flux PM machine.

**8:55AM***Reduction of Cogging Torque in Transverse Flux Machines by Stator and Rotor Pole Shaping [#396]*  
Cristofaro Pompermaier, Jamie Washington, Lars Sjoeberg and Nabeel Ahmed   
, Hoganas AB, Sweden; Hoganas Great Britian Ltd., United Kingdom; Newcastle University, United Kingdom

This paper presents a method of reducing the cogging torque of transverse flux machines by shaping the poles of the rotor. A number of different techniques are presented and simulated. These simulations are verified by the construction of a number of rotors from which measured results have been obtained. Further to this, the rotors are applied to machines with different cogging torque reduction techniques applied to the stator. Measurements of cogging torque have been taken in order to assess the overall effectiveness of each technique.

**9:20AM***Design Considerations of a Transverse Flux Machine for Direct Drive Wind Turbine Applications [#1288]*  
Tausif Husain, Iftekhar Hasan, Yilmaz Sozer, Iqbal Husain and Eduard Muljadi   
, University of Akron, United States; North Carolina State University, United States; National Renewable Energy Lab, United States

This paper presents the design considerations of a double-sided transverse flux machine (TFM) for direct-drive wind turbine applications. The TFM has a modular structure with quasi-U stator cores and ring windings. The rotor is constructed with ferrite magnets in a flux-concentrating arrangement to achieve high air gap flux density. The design considerations for this TFM with respect to initial sizing, pole number selection, key design ratios, and pole shaping are presented in this paper. Pole number selection is critical in the design process of a TFM because it affects both the torque density and power factor under fixed magnetic and changing electrical loading. Several key design ratios are introduced to facilitate the design procedure. The effect of pole shaping on back-emf and inductance is also analyzed. These investigations provide guidance toward the required design of a TFM for direct-drive applications. The analyses are carried out using analytical and three-dimensional finite element analysis. A prototype is under construction for experimental verification.

**9:45AM***Analytical Model Based Design Optimization of a Transverse Flux Machine [#1299]*  
Iftekhar Hasan, Tausif Husain, Yilmaz Sozer, Iqbal Husain and Eduard Muljadi   
, University of Akron, United States; North Carolina State University, United States; National Renewable Energy Lab, United States

This paper proposes an analytical machine design tool using magnetic equivalent circuit (MEC)-based particle swarm optimization (PSO) for a double-sided, flux- concentrating transverse flux machine (TFM). The magnetic equivalent circuit method is applied to analytically establish the relationship between the design objective and the input variables of prospective TFM designs. This is computationally less intensive and more time efficient than finite element solvers. A PSO algorithm is then used to design a machine with the highest torque density within the specified power range along with some geometric design constraints. The stator pole length, magnet length, and rotor thickness are the variables that define the optimization search space. Finite element analysis (FEA) was carried out to verify the performance of the MEC-PSO optimized machine. The proposed analytical design tool helps save computation time by at least 50% when compared to commercial FEA-based optimization programs, with results found to be in agreement with less than 5% error.

Control of Electric Drives II

Thursday, September 22, 8:30AM-10:10AM, Room: 101CD, Chair: Marko Hinkkanen, Pinjia Zhang

**8:30AM***A Novel Six-Phase Inverter System for High-Power Synchronous Motor Drives [#494]*  
Yumei Song, Xiaojie You, Xizheng Guo and Jian Wang   
, Beijing Jiaotong University, China

Load commutated inverters with multiple three-phase configurations are widely used in high-power synchronous motor drives due to its robustness and reliability. However, harmonic problems, poor starting performance and the limited upper frequency are the issues to be addressed. In this paper, a novel six-phase inverter system, consisting of two main three-phase inverters and an additional five-level reinjection circuit, is proposed. The reinjection circuit which generates five current steps is introduced in this study. To note, the lowest current level is zero to ensure the zero current switching of the main inverters. Therefore, the starting performance and torque quality of the synchronous motor are greatly improved. Moreover, the limit of upper frequency is raised since the mutual interaction between stator windings is eliminated during commutation.

**8:55AM***State-Space Flux-Linkage Control of Bearingless Synchronous Reluctance Motors [#388]*  
Seppo Saarakkala, Maksim Sokolov, Marko Hinkkanen, Jari Kataja and Kari Tammi   
, Aalto University School of Electrical Eng., Finland; VTT Technical Research Centre of Finland, Finland; Aalto University School of Engineering, Finland

This paper deals with a model-based state-space flux-linkage control of a dual three-phase-winding bearingless synchronous reluctance motor. Analytical tuning rules for the state feedback, integral action, and reference feedforward gains are derived in the continuous-time domain. The proposed method is easy to apply: the desired closed-loop bandwidth together with the estimated magnetic-model of the motor are required. Furthermore, the proposed method automatically takes into account the mutual coupling between the two windings. A simple digital implementation is provided and the robustness of the proposed control method against the system parameter inaccuracies and eccentric rotor positions is analyzed. The proposed controller design is evaluated by means of simulations by keeping in mind the most important aspects related to an experimental evaluation.

**9:20AM***Current Harmonic Compensation for n-Phase Machines With Asymmetrical Winding Arrangement [#639]*  
Alejandro G. Yepes, Jesus Doval-Gandoy, Fernando Baneira, Diego Perez-Estevez and Oscar Lopez   
, University of Vigo, Spain, Spain

Multiphase machines (MPMs) have become serious contenders in several applications, such as offshore wind energy and electric vehicles. Low-order current harmonics arise in actual drives due to converter and machine nonlinearities, thus producing losses and torque ripple. In comparison to threephase machines, in MPMs this effect is aggravated because of the existence of low-impedance subspaces. To cancel these harmonics, a multiple resonant controller (RC) (MRC) structure has recently been proposed for MPMs, which combines RCs and synchronous frames (SFs). The MRC scheme allows a significant computational saving in comparison to the multiple SF (MSF) strategy, which includes a proportional-integral controller in an SF per each harmonic. However, such MRC method is only suitable for MPMs with symmetrical winding arrangement (SWA), while asymmetrical winding arrangement (AWA) is also a common choice. In this paper, the MRC strategy is extended to MPMs with AWA. Different neutral configurations, whose effect on the harmonic mapping is more complicated than for SWAs and has hardly been studied so far, are considered. The optimum combinations of frequencies at which the RCs and the SFs should be tuned for AWAs are assessed. Simulation results are provided.

**9:45AM***Post-fault operation strategy for single switch open circuit faults in electric drives [#1316]*  
Heinrich T. Eickhoff, Roland Seebacher, Annette Muetze and Elias G. Strangas   
, Graz University of Technology, Austria; Michigan State University, East Lansing, MI, United States

Single switch open circuit faults in three-phase AC drives lead to undesired effects and potentially to a total failure of the drive. This paper proposes a post-fault operation strategy for such faults with the focus on the limitation of losses after the reconfiguration and thereby an extension of the possible range of operation. The performance of the strategy is shown both via simulations and experiments.

Power Packaging

Thursday, September 22, 8:30AM-10:10AM, Room: 202C, Chair: Douglas C Hopkins, Giuseppe Chimento

**8:30AM***A Quasi-online Method of Thermal Network Parameter Identification of IGBT Module [#385]*  
Tengfet Li, Xiong Du, Cheng Zeng, Pengju Sun and Heng-Ming Tai   
, Chongqing University, China; University of Tulsa, United States

The previous proposed method for thermal network parameter identification of IGBT module in [1] is based on the pre-knowledge of heat sink's thermal parameter, which neglected the aging effect of heat sink. This paper improved the identification method in [1]and make the improved method be applicable to systems without acknowledge of heat sink's thermal parameter. The theoretical analysis got the relationship between the thermal network parameter and the time constants of junction temperature when cooling down. We show that the thermal network parameters can be identified in three different cooling conditions. Furthermore, some experiments on an IGBT module were tested and discussed. The obtained RC parameters are in good agreement with the results by JESD51-14 method. The proposed method is based on the information of junction temperature when cooling off. Moreover, the cooling curve of junction temperature can be obtained when the IGBT is out of working, which real exists in some converters. Therefore, the proposed method can be applied in quasi-online.

**8:55AM***Direct-cooled power module with a thick Cu heat spreader featuring a stress-suppressed structure for EV/HEV inverters [#350]*  
Keiichiro Numakura, Kenta Emori, Yusuke Yoshino, Yasuaki Hayami and Tetsuya Hayashi   
, Nissan Motor Co., Ltd., Japan

This paper presents direct-cooled power module technologies that satisfy the requirements for lower thermal resistance and stress relaxation, especially for small die size semiconductors (e.g. Silicon Carbide (SiC)). The power module structure features a thick Copper (Cu) heat spreader located under the semiconductor chip for lower thermal resistance and a thin closed Aluminum (Al) water jacket for stress relaxation. And a prototype power module was fabricated using a thick Cu heat spreader that reduces thermal resistance by 34% compared with conventional direct-cooled power modules. It was also shown that using a thin closed Al water jacket (multi-port tube) achieves the same level of stress as conventional power modules, thereby mitigating the stress-strain and solder cracking induced by the metal junctions with a thick Cu structure.

**9:20AM***Impact of Poly-Crystalline Diamond within Power Semiconductor Device Modules in a Converter [#1560]*  
Mark Robert Sweet, Kalyani Menon and Ekkanath Madathil Sankar Narayanan   
, University of Sheffield, United Kingdom; Rolls-Royce, United Kingdom

This paper presents the finding of thermal characterization of polycrystalline diamond for power semiconductor device modules in a converter. Comparisons of measured thermal performance of two diamond demonstrators, consisting of metalized diamond tiles attached to aluminum and copper forced air cooled heat sinks; show that power dissipation can be increased from 278W to 535W when compared to commercial products operating at a case temperature of 100oC and a maximum junction temperature of 175oC. Detailed converter simulations of a two level three-phase inverter driving a 15kW permanent magnet machine shows that using diamond can increase active power density from 13kW/kg to 17kW/kg at a coolant temperature of 100oC and a flowrate of 6 liters per minute.

**9:45AM***A Novel 3D Structure for Synchronous Buck Converter Based on Nitride Gallium Transistors [#1034]*  
Clement Fita, Pierre-Olivier Jeannin, Pierre Lefranc, Edith Clavel and Johan Delaine   
, G2elab, France; G2ELAB, France

In this paper a novel power loop structure design is proposed and analyzed for converters based on Nitride Gallium transistors. Thanks to its innovative way to place the decoupling capacitors and the GaN devices, the proposed structure shows better results in terms of parasitic loop inductance than a classical 2-D power loop structure, leading to lower voltage stress over the GaN transistors (1,46 nH for the 3-D structure against 5,82 nH for the 2-D one). Moreover, this design generates lower common mode disturbances, which is experimentally demonstrated with EMC tests. Eventually, efficiency is investigated making comparison for the same experimental conditions.

Magnetics I

Thursday, September 22, 8:30AM-10:10AM, Room: 102A, Chair: John Siefken, Charles Sullivan

**8:30AM***NiCuZn Ferrite Cores by Gelcasting: Processing and Properties [#565]*  
Lanbing Liu, Yi Yan, Khai Ngo and Guo-Quan Lu   
, Virginia Tech, United States

We used gelcasting, a processing technology for fabricating ceramic parts without pressure, to make NiCuZn ferrite cores, which are traditionally made by a process that requires high hydrostatic pressure. A commercial NiCuZn ferrite powder was mixed with water, dispersant, and organic monomers to form a slurry, and then cast into a mold of toroid shape followed by sintering at 900, 950, and 1000oC respectively for two hours. The sintered core mass density was found to increase with sintering temperature. The magnetic properties of the cores, i.e. complex permeability and core- loss density, were measured. We found that the real part of the permeability increased with sintering temperature from about 44 at 900oC to 77 at 1000oC. The core-loss density data at 5 MHz showed that the cores sintered at 950oC had the lowest core-loss density, about 50% lower than that of a commercial NiZn ferrite (4F1) core. Since gelcasting does not require pressure and is scalable and low cost, it has the potential to make magnetic cores with intricate shapes and sizes for desired coupling of magnetic fluxes to improve efficiency and power-density of power electronics converters.

**8:55AM***Low-Capacitance Planar Spiral Windings Employing Inverse Track-Width-Ratio [#1092]*  
Samuel Robert Cove and Martin Ordonez   
, University of British Columbia, Canada

Planar spiral windings have garnered a significant amount of attention recently due to the popularity of slim consumer electronics combined with their low-profile, high reproducibility, and simple manufacturing. Unfortunately they still suffer from high internal capacitance which limits their use at high frequencies. This work presents the novel inverse Track- Width-Ratio (TWR) planar structure, which greatly reduces the undesired capacitance of multi-layer planar spiral windings by changing the turn widths. The amount of overlapping copper is ultimately reduced with the proposed technique, especially in the areas where the capacitance is the highest, resulting in significantly improved performance. Analytical models for the resistance of planar spiral windings with inverse TWR employed are presented and used as inputs into Finite Element Analysis to predict the capacitive behaviour of the structure. These results are compared to experimental results obtained from an impedance analyzer and a capacitance reduction up to 50% is exhibited, with a reduction in ac resistance by 20%.

**9:20AM***On-Chip Transformers with Shielding Structures for High dV/dt Immunity Isolated Gate Drive [#1385]*  
Rongxiang Wu, Julong Chen, Niteng Liao and Xiangming Fang   
, Univ of Electron Sci and Tech of China, China; Shenzhen CoilEasy Technologies, Co. Ltd., China

High dV/dt immunity is desired for isolated gate driving of next generation fast switching power devices. This requires the on-chip isolation transformer to have a small capacitive coupling between the coils. Therefore, in this paper, on-chip transformers with solid ground shield (SGS) and patterned ground shield (PGS) structures are proposed and studied. Simulation results show that the SGS achieves perfect capacitive shielding and therefore excellent dV/dt immunity at the cost of 23% to 31% lower inductances and a 16% lower voltage gain, while the PGS reduces the capacitive coupling by 10 times and therefore achieves a 10 times better dV/dt immunity without notably sacrificing the inductances and the voltage gain.

**9:45AM***Additive Manufacturing of Toroid Inductor for Power Electronics Applications [#472]*  
Yi Yan, Khai Ngo, Yunhui Mei, Guo-Quan Lu and Jim Moss   
, Virginia Tech, United States; Tianjin University, China; Texas Instruments, United States

A commercial multi-extruder paste-extrusion 3D printer was used to process both metal and magnetic pastes into 3D structures of magnetic components for power electronics circuits. For the magnetic core, we formulated a permalloy powder filled benzocyclobutene composite in the form of paste, termed poly-mag paste, as a feed stock for the printer; while for the conductive winding feed stock, we used a commercial nanosilver paste. A toroid inductor was 3D-printed by using the metal and magnetic pastes, and it was cured at 250 degree C for a half hour without any external pressure to form the structure. The inductance of the 3D printed toroid inductor was measured to be about 110.3nH. The DC resistance of the winding was 0.28 Ohm. Both the winding and core magnetic properties can be improved by adjusting the feed paste formulations and their flow characteristics and fine-tuning the printer parameters, such as motor speeds, extrusion rate, and nozzle sizes.

Grid Synchronization

Thursday, September 22, 8:30AM-10:10AM, Room: 202E, Chair: Behrooz Mirafzal, Tsorng-Juu Liang

**8:30AM***A New Phase-Locked Loop Method for Three-Phase System [#124]*  
Hongyan Zhao, Trillion Q. Zheng, Yan Li, Hong Li and Shi Pu   
, Beijing Jiaotong University, China

Stability and rapidity of phase angle detection in grid synchronization system is very important, especially when grid voltage is under adverse conditions. This paper presented a fast direct calculation phase-locked loop (FDC-PLL) method which can detect phase angle directly from the corresponding relationship between the absolute value of grid voltage and the phase angle. And the d-q conversion is not needed in FDC-PLL. Moreover, when gird voltage is unbalanced or distorted, the positive-sequence fundamental component (PSFC) of grid voltage is extracted through double second order generalized integrator (DSOGI), and phase angle is calculated by using PSFC. As a consequence, the effectiveness and feasibility of the presented PLL algorithm is verified by simulations and experiments.

**8:55AM***A New Second-Order Generalized Integrator Based Quadrature Signal Generator With Enhanced Performance [#1069]*  
Zhen Xin, Zian Qin, Minghui Lu, Poh Chiang Loh and Frede Blaabjerg   
, Aalborg University, Denmark

Due to the simplicity and flexibility of the structure of the Second-Order Generalized Integrator based Quadrature Signal Generator (SOGI-QSG), it has been widely used over the past decade for many applications such as frequency estimation, grid synchronization, and harmonic extraction. However, the SOGI-QSG will produce errors when its input signal contains a dc component or harmonic components with unknown frequencies. The accuracy of the signal detection methods using it may hence be compromised. To overcome the drawback, the First-Order System (FOS) concept is first used to illustrate the principle of the SOGI-QSG, based on which, an improved Second- Order SOGI-QSG (SO-SOGI-QSG) is then proposed by referring the relationship of the standard FOS and the second-order system. The proposed SO-SOGI-QSG inherits the simplicity of the SOGI-QSG, while it has much stronger attenuation ability for both low- and high-frequency components. A detailed parameter design procedure for the SO- SOGI-QSG is provided in this paper as well. The effectiveness of the proposed SO-SOGI- QSG is finally validated by experimental results.

**9:20AM***A Modified SRF-PLL for Phase and Frequency Measurement of Single-Phase Systems [#104]*  
Md. Rasheduzzaman, Sami Khorbotly and Jonathan Kimball   
, Missouri University of Science and Technology, United States; Valparaiso University, United States

In this work, a single phase phase-lockedloop (PLL) that uses a low-pass notch filter is proposed. The new PLL was derived from the synchronous reference frame PLL (SRF-PLL) in which the dq axis components were generated using the alpha-beta reference signals. The single-phase grid voltage was used as the alpha component, whereas the beta component was derived by delaying the grid voltage by 90 degrees in phase. The dynamics of the proposed PLL were compared to those of the SRF-PLL. The frequency measurement using the new PLL showed better performance over the SRF-PLL and a second-order generalized integrator (SOGI) PLL. The proposed PLL displayed better performance under both variable frequency and distorted grid voltage conditions. Experimental results were used to validate the dynamics obtained from the simulation results. The proposed method adds very little complexity to the conventional SRF-PLL.

**9:45AM***Influence Of Double-Line Frequency Power Oscillation In Photovoltaic Generator Efficiency And H-Bridge VSI Performance [#622]*  
Luciano Alves, Montie Vitorino, Marcus Oliveira, Mauricio Correa and Gutemberg Goncalves   
, Federal University of Campina Grande, Brazil; Tocantins Federal Institute of Technology, Brazil

In this work it is presented a theoretical and experimental investigation of the influence of the low power oscillation due to the pulsating single-phase energy flow in a H-bridge voltage source inverter that operates connected to the grid and is fed by photovoltaic (PV) panels. That oscillation can be responsible for efficiency reduction of PV generators connected to the DC-bus of the inverter, as well as degrades its AC output voltage quality. Experimental results are provided to validate the theoretical approach and to evaluate the performance and quantify energy gain by proposing a method to improve the amount of energy extracted from a PV generator even with low frequency oscillation.

Thursday, September 22, 10:30AM-12:10PM

Electric Machines for Wind Power Systems

Thursday, September 22, 10:30AM-12:10PM, Room: 203AB, Chair: Ion Boldea, Pragasen Pillay

**10:30AM***Comparison Analysis of PM Transverse Flux Outer Rotor Machines with and without Magnetic Shunts [#475]*  
Oleksandr Dobzhanskyi, Gouws Rupert and Amiri Ebrahim   
, Doctor, Ukraine; Professor, South Africa; Ass. Professor, United States

This paper presents electromagnetic analysis of two permanent magnet transverse flux outer rotor machines with and without magnetic shunts. The research started with designing and analysing a permanent magnet transverse flux machine with inner rotor, previously patented by J. Giearas in 2010.

**10:55AM***A Generator-Converter Design for Direct Drive Wind Turbines [#1057]*  
Akanksha Singh and Behrooz Mirafzal   
, Kansas State University, United States

In this paper, a new generator-converter system for direct drive wind turbines in order to decrease the capital cost and improve the system reliability is presented. The grid-side Voltage Source Inverter (VSI) is replaced by a single-stage boost inverter. This provides flexibility to design a low-voltage generator and thus decreasing the number poles required in the generator. A 1.5MW generator for the proposed system is designed using Finite Element (FE) computations. This design is compared with an existing 1.5MW permanent magnet generator for direct drive wind turbine. The proposed system is supported with set of finite element computations and MATLAB/Simulink simulations.

**11:20AM***Gearbox Fault Diagnosis Using Vibration and Current Information Fusion [#1685]*  
Yayu Peng, Wei Qiao, Liyan Qu and Jun Wang   
, University of Nebraska-Lincoln, United States

This paper proposes a novel vibration and current information fusion-based fault diagnostic method for drivetrain gearboxes. First, two multiclass support vector machines (SVMs) are designed to output the probabilities of different fault (or health condition) classes according to the input features extracted from a vibration signal and a current signal collected from the condition monitoring system, respectively. The Dempster-Shafer (D-S) theory is then applied to fuse the probabilistic outputs of two SVMs to get the final fault diagnostic result. Experiments are conducted for a gearbox with different types of fault, where a gearbox vibration signal and a generator current signal are collected to prove the effectiveness of the proposed method. Results show that the proposed method is more robust and reliable than the traditional methods of using a single sensor or a single type of sensor for gearbox fault diagnosis.

**11:45AM***Bearing Fault Diagnosis of Direct-Drive Wind Turbines Using Multiscale Filtering Spectrum [#1097]*  
Jun Wang, Yayu Peng and Wei Qiao   
, University of Nebraska-Lincoln, United States

Bearing fault diagnosis of direct-drive (i.e., no gearbox) wind turbines is a challenging issue due to the varying shaft rotating frequency (SRF) caused by the erratic wind environment. To solve the spectrum smearing problem of the SRF- related components and remove the disturbances of the SRF-unrelated components in a measured signal, this paper proposes a novel method, called multiscale filtering spectrum (MFS), to obtain the weighted energy distribution of the mono-component signals within a local order range based on the Vold-Kalman filter (VKF). First, the instantaneous SRF of the wind turbine is estimated from a generator current signal. Then, a VKF-based multiscale filter bank is designed according to the center frequencies corresponding to the SRF at different scales. The mono-component signals whose frequencies are continuous multipliers of the SRF are subsequently extracted from the envelope of the measured current or vibration signal. Finally, a weighted energy spectrum is constructed within the selected order range, from which possible bearing fault characteristic orders can be identified. Simulation and experiment results show that the proposed new MFS method can enhance the characteristic orders and suppress the noise and, therefore, has better performance than the traditional angular resampling method for bearing fault diagnosis of direct-drive wind turbines under varying speed conditions.

Converter Topologies for Energy Storage Systems

Thursday, September 22, 10:30AM-12:10PM, Room: 203C, Chair: Behrooz Mirafzal, Ion Boldea

**10:30AM***Design Considerations of an Isolated GaN Bidirectional DC-DC Converter [#233]*  
Fei Xue, Ruiyang Yu and Alex Q. Huang   
, North Carolina State University, United States

This paper investigates three design considerations of a novel bidirectional dc-dc converter for distributed energy storage device. They are the layout for minimum loop inductance and heat dissipation, gate drive power supply for high side Gallium-Nitride (GaN) device and high resolution digital PWM control methodology. The special package of the available GaN devices requires a PCB layout method that takes into account the thermal design as well as the switching loop inductance. Besides, the high dv/dt will introduce a circulating current in the high-side gate drivers and power supplies. This current should be minimized. Furthermore, conventional digital PWM modules is not precise enough for high frequency (usually >50kHz) converter modulation and will cause limited cycle oscillation. A high resolution digital phase-shift modulation scheme is utilized to improve the resolution of the phase-shift control for the 150 kHz converter. In the end, an optimized engineering design method is proposed. The experimental results are analyzed on a 1kW bidirectional dc-dc converter to verify the concepts.

**10:55AM***Flexbattery - Merging Multilevel Power Conversion and Energy Storage [#397]*  
Erik Lemmen, Jorge L. Duarte and Elena A. Lomonova   
, Eindhoven University of Technology, Netherlands

This paper describes a ``flexbattery'' modular battery pack concept that integrates the function of energy storage, active cell balancing, and bidirectional multilevel power conversion. As a result, the flexbattery pack does not have a positive or negative terminal, but terminals that can operate at arbitrary voltage levels, both positive or negative. Since each connection terminal can generate a variable voltage within a certain range, the system can also supply ac voltage. Therefore, with appropriate control this innovative flexbattery could be directly applied to an electrical motor. Also, the flexbattery pack can be charged from any voltage level within the nominal output range of the pack, both dc or ac. The elementary flexbattery unit is introduced and analyzed together with the operation of a pack. Additionally, the concept has been experimentally verified with a 120 W three-unit, nine- level prototype under both ac and dc operation.

**11:20AM***A Novel Modular Dual Active Bridge (DAB) DC-DC Converter with DC Fault Ride-Through Capability for Battery Energy Storage Systems [#957]*  
Yuxiang Shi and Hui Li   
, Florida State University, United States

This paper proposes a novel modular dual-active-bridge (DAB) dc-dc converter for spilt-battery energy storage system (BESS) in medium-voltage dc (MVDC) grid application. Compared to modular cascaded DAB converter, the proposed topology has current-fed DAB characteristics, with directly dc current control to achieve dc fault ride-through capability. In addition, the proposed converter exhibits favorite features of DAB converter such as galvanic isolation, soft-switching condition and small passive components. The operating principle is described in details, and the corresponding control system is developed to realize the power flow and balancing control. A case study of 500 kW, 20 kHz BESS based on proposed converter is simulated for validation.

**11:45AM***A High Current Bidirectional DC-DC Converter for Concept Demonstration of Grid-Scale SMES Systems [#1457]*  
Yu Du, Eddy Aeloiza and VR V. Ramanan   
, ABB Inc., United States

This paper presents the development and testing results of the high current bidirectional DC-DC converter system for concept demonstration of the next generation high current superconducting magnetic energy storage (SMES) system under a program funded by ARPA-E. The grid-scale SMES system could be enabled by new superconductor materials and manufacturing technologies and targets MWh level energy storage applications. In the SMES power conversion system, interleaving of three-level NPC DC-DC converters with voltage reversal for bidirectional power flow is proposed to meet the requirements of new SMES coil systems, such as high current and voltage ratings, low current and voltage ripples, wide operation range, and modularity. To demonstrate the concept, a 700A/12V SMES lab coil prototype and a 6-channel interleaved bidirectional DC- DC converter with three-level NPC modules have been developed and tested. The paper focuses on the detail design and implementation of the high current DC-DC converter system including the power stage, passive components and control electronics, and the testing results for the proposed converter solution for SMES applications.

AC Microgrids II: Sharing and Coordination

Thursday, September 22, 10:30AM-12:10PM, Room: 203DE, Chair: Pedro Rodriguez, Hui Li

**10:30AM***Harmonic power sharing with Voltage Distortion Compensation of Droop Controlled Islanded Microgrids [#605]*  
Hassan Moussa, Jean-Philippe Martin, Serge Pierfederici and Nazih Moubayed   
, Lorraine University, France; Lebanese University, Lebanon

Harmonics are found to have deleterious effects on power system equipment including transformers, capacitor banks, rotating machines etc. This paper describes the voltage distortion generated by nonlinear loads and proposes a new Harmonic Droop Control to reduce the voltage harmonic distortion at the point of common coupling (PCC) and to share the harmonic power between parallel islanded Inverters controlled by classical frequency droop method. Simulation and experimental results are presented to show the competence of the proposed algorithm in achieving harmonic power sharing and in improving the voltage harmonic distortion at the PCC.

**10:55AM***Novel Active Synchronization Strategy for Multi-Bus Microgrid with Distributed Cooperation Control [#355]*  
Chaolu Zhong, Yao Sun, Ying Chen, Mi Dong, Ming Liu and Xiaochao Hou   
, Central South University, China

This paper presents a novel active synchronization control strategy of multi-bus microgrid based on distributed cooperation technology. The method can reconnect microgrid back to utility grid (UG) seamlessly with sparse communication channels. Through the cross product of voltage vectors in the synchronizer, the frequency and phase of microgrid can track the main grid simultaneously. The voltage differences of UG and point of common coupling (PCC) are fed back to subsequent PI controllers to generate synchronization correction signals, which are only sent to the leader distributed generators (DG). Meanwhile, each DG exchanges information with its neighbors. The voltage of PCC can follow and synchronize with the main grid for a seamless transition and all DGs achieve the consensus behavior. Compared with traditional synchronization methods, the proposed method obviates complex communication network and improves flexibility and redundancy. Simulation results are presented to verify the effectiveness of the proposed method.

**11:20AM***An Inverter-Current-Feedback based Reactive Power Sharing Method for Parallel Inverters in Microgrid [#627]*  
Qicheng Huang and Kaushik Rajashekara   
, University of Texas at Dallas, United States

This paper proposes a method to improve the reactive power sharing performance of parallel inverters in a low-voltage islanded microgrid. The proposed method utilizes only the output capacitor voltage and the inverter side current to implement the droop control loop, virtual impedance loop and inner voltage control loop for inverter control. This eliminates the need for extra grid side current sensors and therefore reduces implementation costs. A frequency adaptive reactive power compensation module is added to the reactive power droop loop to improve the accuracy of reactive power sharing. The system stability with the proposed method is analyzed based on the Thevenin equivalent model of the voltage source inverters (VSIs). Moreover, a second- order general integrator (SOGI) filter is introduced into the inverter current based virtual impedance loop to improve the stability. Simulation and experimental results are presented to verify the effectiveness of the method.

**11:45AM***Distributed Voltage Control and Load Sharing for Inverter-Interfaced Microdrid with Resistive Lines [#804]*  
Mohammad S. Golsorkhi, Qobad Shafiee, Dylan D.C. Lu and Josep M. Guerrero   
, School of Electrical and Information Engineering, Australia; Department of Electrical and Computer Engineerin, Iran; The Institute of Energy Technology, Aalborg Univ, Denmark

This paper proposes a new distributed control method for coordination of distributed energy resources (DERs) in low-voltage resistive microgrids. The proposed framework consists of two level structure; primary and secondary control. Unlike the existing distributed control methods, the proposed method is based upon the practical assumption of resistive network impedance. In this context, a V-I droop mechanism is adopted in the primary control level, where GPS timing is used to synchronize the control agents. A new distributed secondary control method based on consensus protocol is introduced to improve the voltage regulation and load sharing accuracy of the V-I droop method. In this method, the d-axis components of the voltage is altered so as to regulate the average microgrid voltage to the rated value while guarantying proper sharing of active power among the DERs. Additionally, the q-axis component of voltage is adjusted to perform proper current and, accordingly reactive power sharing. The proposed control methodology accounts for the distribution line impedances. It features a plug-and-play environment; prior system knowledge is not required, and an arbitrary DER can enter the microgrid without any need for additional synchronization mechanisms. An AC microgrid is prototyped to experimentally demonstrate the efficacy of the proposed method.

Batteries and Battery Management for Transportation Electrification II

Thursday, September 22, 10:30AM-12:10PM, Room: 102D, Chair: Oliver Gross, Omer Onar

**10:30AM***Accurate Battery Parameter Estimation with Improved Continuous Time System Identification Methods [#699]*  
Bing Xia, Xin Zhao, Raymond de Callafon, Hugues Garnier, Truong Nguyen and Chris Mi   
, San Diego State University, United States; University of California San Diego, United States; University of Lorraine, France

The modeling of Lithium-ion batteries usually utilizes discrete-time system identification methods to estimate parameters of discrete models. However, in real applications, there is a fundamental limitation of the discrete-time methods in dealing with sensitivity when the system is stiff and the storage resolutions are limited. To overcome this problem, this paper adopts direct continuous-time system identification methods to estimate the parameters of equivalent circuit models for Lithium-ion batteries. Compared with discrete- time system identification methods, the continuous-time system identification methods provide more accurate estimates to both fast and slow dynamics in battery systems and are less sensitive to disturbances. A case of a second order equivalent circuit model is studied which shows that the continuous-time estimates are more robust to high sampling rates, measurement noises and rounding errors. In addition, the estimation by the conventional continuous-time least squares method is further improved in the case of noisy output measurement by introducing the instrumental variable method. Simulation and experiment results validate the analysis and demonstrate the advantages of the continuous-time system identification methods in battery applications.

**10:55AM***A Real World Technology Testbed for Electric Vehicle Smart Charging Systems and PEV-EVSE Interoperability Evaluation [#1461]*  
Theodore Bohn and Hal Glenn   
, Argonne National Laboratory, United States; 2G Engineering, United States

Global sales of electric vehicles passed the 1 million unit mark in 2015. These grid-sourced electric vehicles operators require reliable access to seamless delivery of electricity to their vehicles for dependable transportation. Electrical utilities and other electrical distribution infrastructure owner/operators require the electrical vehicles using their services to be non- disruptive with reasonable return on investment revenues. Standards Defining Organization (SDO) committees are composed of subject matter experts that formalize requirements for the respective standards topic, based on needs of the stakeholders. Validation of standards, component-system compliance to standards, and interoperability of systems between standards requires testing. This testing can be simulation or model based as well as component and system level evaluation. This paper describes requirements and challenges to build a real-world testbed for EV-smartgrid interoperability assessment. AC, DC, and Wireless charging methods are addressed as well of balance of system topic such as grid impacts, metrology, dispatch of resources, and vehicle-infrastructure communication.

**11:20AM***Modeling of Low-Temperature Operation of a Hybrid Energy Storage System with a Butler-Volmer Equation Based Battery Model [#1472]*  
Phillip Kollmeyer, Anantharaghavan Sridhar and Thomas Jahns   
, University of Wisconsin-Madison, United States

Lithium-ion battery performance is significantly reduced at low temperatures, where substantially increased resistance reduces power capability and lithium plating causes charging limitations. To reduce the low-temperature limitations of an electric vehicle battery pack, a hybrid energy storage system consisting of a battery pack, an ultracapacitor pack, and a dc/dc converter is investigated. A low-temperature battery model that includes a nonlinear resistance based on the Butler-Volmer equation and an ultracapacitor model are developed, and the model parameters are experimentally measured for temperatures from -20 to 25 degrees Celsius. The models are then appropriately scaled for a full-size electric vehicle and paired with a dc/dc converter loss model. The optimal power split is determined for various drive cycles using a dynamic programming optimization algorithm. It is shown, using both analytical and experimental results, that the hybrid energy storage system is an excellent approach for substantially reducing the total energy storage system losses at low temperatures, as well as increasing regenerative braking energy capture, reducing output power limiting, and increasing vehicle range.

**11:45AM***Voltage and Current Signals De-noising with Wavelet Transform Matrix for Improved SOC Estimation of Lithium-ion Battery [#958]*  
Xiang Cheng, Zhouyu Lu, Zhiliang Zhang, Dongjie Gu and Yang Yang   
, Nanjing University of Aeronautics Astronautics, China

The electromagnetic environment of the lithium-ion battery in the Electric Vehicles (EVs) is severe. Moreover, the load current of the battery in the EVs changes drastically and randomly depending on the EV driving condition. As a result, the voltage and current signals measured by the Battery Management System (BMS) normally contain the noise such as the white noise. This results in the estimation error of the State of Charge (SOC). A new voltage and current de-noising approach based on Wavelet Transform Matrix (WTM) is proposed in this paper to improve the accuracy of the SOC estimation using Extended Kalman Filter (EKF) algorithm. This approach reduces the computation complexity and the measuring noise is de-noised effectively. It was validated by the experimental results on a 1665132 model laminated Li(NiCoMn)O2 battery with the rated capacity of 200 Ah and rated voltage of 3.6 V. The voltage of the battery ranges from 3.2 V to 4.2 V. The accuracy of the SOC estimation is improved significantly and the error is limited within 1.5% less than the error of 6% by EKF without de-noising.

Multi-Phase Inverter

Thursday, September 22, 10:30AM-12:10PM, Room: 202A, Chair: Babak Parkhideh, Raja Ayyanar

**10:30AM***Improved r-Z-Source Inverter [#354]*  
Zeeshan Aleem and Moin Hanif   
, University of Cape town, South Africa; University of Cape Town, South Africa

This paper proposes a new improved gamma Z-source inverter (rZSI) that overcomes the drawbacks faced by the conventional rZSI. The improved rZSI provides continuous input current and higher voltage gain compared to the conventional inverter. Moreover, an extra diode provides a path for the energy in the leakage inductance to flow to the load in a non oscillatory manner and reduces the voltage spikes across the switches. The improved rZSI compared to the conventional rZSI can use a higher modulation index and consequently a lower shoot through duty for the same input voltage, output voltage and transformer turn ratio, thus, having lower stress across the inverter bridge. It has an improved power factor and better output waveform quality. To validate the advantages of the proposed inverter, analytical, simulated and experimental results are presented.

**10:55AM***High-Frequency Six Pulse DC Link Based Bidirectional Three-Phase Inverter without Intermediate Decoupling Capacitor [#1577]*  
Vatta Kkuni Kanakesh, Anirban Ghoshal, Dorai Babu Yelaverthy, Akshay Kumar Rathore and Ranjit Mahanty   
, National University of Singapore, Singapore; Concordia University, Montreal, Canada; Indian Institute of Technology, BHU, Varanasi, India

Cascaded bidirectional dc-ac converters are commonly used in UPS application and battery chargers for electric vehicles (EV). A bidirectional dual active bridge cascaded three phase converter (DABCC) with six pulse dc link, high reliability and low cost is proposed for applications like line interactive UPS and EV. Power conversion units for such applications use large electrolytic capacitor at high voltage DC bus. Through a novel modulation technique Six Pulse Modulation (SPM), this electrolytic capacitor is eliminated that results in increased reliability, compactness and reduced cost. It needs only single H-bridge and one single-phase transformer at front-end for the required three-phase conversion. SPM technique also increases DC bus utilization and decreases the inverter average switching frequency to 33% when compared to traditional sine PWM. To effectively implement the SPM modulation, a fast dynamic control of dc link voltage is required. For that a coordinated control is implemented. And also the effect of dead time on the inverter terminal voltage for a SPM modulated converter is analyzed and its effect on terminal voltage is presented. To mitigate this effect, a compensation technique based on resonant control is proposed. RMS current stress for high voltage dc link capacitor is studied and it is shown that the capacitor requirement for SPM modulation is lower than the conventional Sine Pulse Width Modulation (SPWM). To validate the proposed control scheme, a 800 W prototype is fabricated. Hardware results are presented to show the effectiveness of the implemented control scheme.

**11:20AM***Closed-Form Equations for Analytical Exploration and Comparison of Switching Power Losses in Flying Capacitor Multicell and Active Neutral-Point-Clamped Multilevel Converters [#1104]*  
Vahid Dargahi, Arash Khoshkbar Sadigh and Keith Corzine   
, Clemson University, United States; Extron Electronics, United States

This study presents closed-form formulas in order to analytically calculate, evaluate, and compare the switching power losses in flying capacitor multicell (FCM) and active neutral-point-clamped (ANPC) converters. The equations are derived on the basis of computing the switching instants of the PWM modulator exploiting the Kapteyn (Fourier-Bessel) series. In this regard, the switching power loss investigation is carried out analytically through the derived closed-form equations, and numerically through simulation results. In order to simulate the switching power losses the numeric approach using curve- fitting method is adopted. Comparative analysis and evaluation of the switching power losses are presented for both of the multilevel converters.

**11:45AM***Advanced Three Level Active Neutral Point Converter with Fault Tolerant Capabilities [#858]*  
Ramin Katebi, Andrew Stark, Jiangbiao He and Nathan Weise   
, Marquette University, United States

A novel fault-tolerant power converter topology is developed based on conventional active neutral point clamped (ANPC) converter. The effect on converter performance due to open/short circuit faults of power devices is investigated. By leveraging the redundant leg in the proposed topology, the lost voltage vectors in the space vector diagram can be restored. This new fault-tolerant topology is capable of maintaining the full output voltage and maximum modulation index during postfault operation stage. A 25-kW converter prototype based on using 1.2kV SiC MOSFETs has been built in the laboratory, and the experimental results verified the efficacy of the proposed fault- tolerant ANPC converter.

AC-AC Converters I

Thursday, September 22, 10:30AM-12:10PM, Room: 202E, Chair: Pat Wheeler, Mattia Ricco

**10:30AM***A Novel Highly Reliable Three Phase Buck-Boost AC-AC Converter [#75]*  
Ashraf Ali Khan and Honnyong Cha   
, Kyungpook National University, Korea (South)

In this paper, a novel three-phase buck-boost ac-ac converter is proposed. It requires only three inductors and six switches. The proposed converter has no current shoot-through related problems and eliminates the PWM dead times, which results in greatly enhanced system reliability. The proposed converter allow the use of MOSFET without conducting body diode, therefore the reverse recovery issues and related loss of MOSFET body diode can be eliminated. The use of MOSFET in conjunction with external diode reduces the power loss, and the converter can be designed at higher switching frequency to reduce the volume of passive components. A 1 kW hardware prototype of the proposed three-phase buck-boost ac- ac converter is fabricated and tested. The detailed analysis followed by experimental results are provided to prove the novelty of the proposed converter.

**10:55AM***Hybrid Bidirectional AC/AC Multilevel Converter [#1463]*  
Ramiar Alaei, S. Ali Khajehoddin and Wilsun Xu   
, University of Alberta, Canada

A new bidirectional multilevel converter topology called Hybrid Multilevel Converter (HMC) suitable for high power AC/AC applications is presented. It is based on cascaded connection of multiple half-bridge submodules in addition to nine thyristor-based low-frequency and soft-switched unfolders in a three-phase version. Compared with a conventional modular multilevel converter (MMC), HMC requires less number of capacitors and IGBTs and also does not inherit the internal unwanted circulating current which obviates the necessity of arm inductors. A control strategy is developed which guarantees the capacitor voltage balancing in different operating conditions. The practicality of the modified SMMC, as well as the effectiveness of the voltage balancing control, is confirmed by simulation.

**11:20AM***A Reliable Cascaded AC-AC Converter [#356]*  
Ashraf Ali Khan, Honnyong Cha, Sanghoon Kim and Hafiz Furqan Ahmed   
, Kyungpook National University, Korea (South)

This paper presents a new type of cascaded PWM ac-ac converter with phase-shift PWM control. It can reach high output voltage by cascading single-phase units of low voltage rating devices. The proposed converter does not sense current/voltage polarity, and does not require current/voltage sensors and lossy snubbers for commutation, thereby the control complexity can be decreased. It has no shoot- through problem and eliminates the PWM dead times, which leads to greatly enhanced system reliability. The phase shift PWM control is also proposed for the proposed converter to reduce the volume of passive components, and current and voltage ripples. In order to verify the robustness of the proposed converter, a 1 kW hardware prototype converter having two-unit cell structure is fabricated and tested

**11:45AM***Parallel AC-AC Three-Phase with Shared-Leg Converters [#773]*  
Edgard Fabricio, Cursino Jacobina, Nady Rocha, Rodolpho Cavalcante and Mauricio Correa   
, IFPB, Brazil; UFCG, Brazil; UFPB, Brazil

Two parallel ac-ac three-phase to three-phase with shared-leg converters are proposed in this paper. They are composed of two parallel three-phase rectifiers, two parallel three-phase inverters, where each group of rectifier and inverter sharing one or two legs, and one or two dc-links. Suitable modelling and control strategy of the system are developed. Compared to the conventional three-phase to three-phase dc-link converter, the proposed topologies permit to reduce: the current and power ratings of the power switches, total harmonic distortion (THD) of grid current and, the semiconductor and dc-link capacitor losses. Simulated and experimental results are also presented in order to validate the analyses.

Modular Multilevel Converters (MMC) II

Thursday, September 22, 10:30AM-12:10PM, Room: 202B, Chair: Juergen Biela, Grain Adam

**10:30AM***A Series HVDC Power Tapping Using Modular Multilevel Converters [#251]*  
Binbin Li, Mingxu Guan, Dianguo Xu, Rui Li, Grain Philip Adam and Barry Williams   
, Harbin Institute of Technology, China; University of Strathclyde, United Kingdom

The concept of HVDC taps drawing small amount of power from HVDC lines to the rural places has been considered for several decades. Most of the earlier tap converters were limited by its loss, cost, reliability, and control difficulties. However, in this paper, the emerging modular multilevel converter (MMC) is adopted as the series HVDC tap, which reveals significantly improved performance and feasibility. Circuit structure and operating principle of this tap are presented, and the control considerations are also discussed. Simulations are given to demonstrate effectiveness of the MMC tap and the proposed control strategies. This tap topology is very promising to find practical use in future HVDC tapping applications.

**10:55AM***A Zero-sequence Voltage Injection Control Scheme for Modular Multilevel Converter Under Submodule Failure [#234]*  
Jinke Li, Xuezhi Wu, Xiuyuan Yao, Long Jing, Xinmin Jin, Wen Wu, Xiaoxing Wang and Shuai Wang   
, Beijing Jiaotong University, China; China Electric Power Research Institute, China

In this paper, a modulation strategy based on zero-sequence voltage injection is proposed for module multilevel converter (MMC). By the proposed method, the remaining capacitor voltages not vary and the line-to-line voltages are balanced. This method is easy to be implemented by adjusting the voltage injection coefficient when SM fault occurs. The coefficient of injected zero-sequence voltage is designed by the number and position of the fault submodules (SMs) and the fault tolerant capability of this method are also discussed. The effectiveness and advantages of proposed method are confirmed with simulation and experiment.

**11:20AM***An Interconnected Observer for Modular Multilevel Converter [#891]*  
Mohamed Trabelsi, Malek Ghanes, Omar Ellabban, Haitham Abu-Rub and Lazhar Ben-Brahim   
, Texas A and M University at Qatar, Qatar; ENSEA, France; Qatar University, Qatar

Modular multilevel converter is an attractive topology for transformer less high voltage applications due to its capability to reach high voltage levels by the use of power semiconductors. Each submodule can be considered as a controlled voltage source where capacitors voltages should be maintained at a certain level for proper operation of the MMC and for fault detection and protection purposes. Besides, the minimization of the circulating current, which does not flow to the load, is crucial to achieve stable and efficient operation of the MMC. Thus, this paper presents a novel Interconnected Observer based Model Predictive Control for a single phase MMC. The newly designed observer is used to estimate the capacitors voltages using the circulating and load currents. This approach introduces the capacitance value of the cell capacitors as a parameter uncertainty toward making the system performance robust with anonymous constant parameters. The estimated capacitors voltages are then used by the proposed MPC algorithm to achieve stable and balanced voltage and for current control with reduced circulating current in various operating conditions. Simulation studies are performed in Matlab Simulink environment to verify the proposed design.

**11:45AM***DC Bus Balancing Control Techniques for the Cascaded Neutral Point Clamped Modular Converter [#920]*  
Meng-Jiang Tsai, Wei-Lun Huang, Hsin-Chih Chen, Ping-Heng Wu and Po-Tai Cheng   
, National Tsing Hua University, Taiwan

This paper investigates different compensation methods for neutral point potential deviation based on modular multilevel single star neutral point clamped-bridge converter. Theoretical analysis indicates injecting an offset for a cell can effectively decrease this deviation, so this research presents different offset-compensation techniques, and evaluates their output performance. Besides, this research also presents a hierarchical voltage balancing control to efficiently process the power flow among cells. Laboratory test results are provided to verify their effectiveness.

DC-DC Isolated: Resonant

Thursday, September 22, 10:30AM-12:10PM, Room: 102C, Chair: Dragan Maksimovic, Yan-Fei Liu

**10:30AM***Step-Down Impedance Control Network Resonant DC-DC Converter Utilizing an Enhanced Phase-Shift Control for Wide-Input-Range Operation [#1447]*  
Jie Lu, Ashish Kumar and Khurram Afridi   
, University of Colorado Boulder, United States

This paper introduces an isolated step-down impedance control network (ICN) resonant dc-dc converter that utilizes enhanced inverter and rectifier phase-shifts to achieve both soft-switching and output voltage regulation. Compared to previously presented ICN converters, which utilize burst-mode control to achieve output voltage regulation, this ICN converter with the proposed enhanced phase-shift control has dramatically reduced output capacitance requirement, simplified the input EMI filter design, and improves converter efficiency. A prototype 1-MHz, 120-W step-down ICN resonant converter designed for an input voltage range of 18 V to 75 V, an output voltage of 12 V, and a 10:1 output power range has been designed, built and tested with both burst-mode control and the proposed enhanced phase-shift control. When operated with the enhanced phase-shift control, the prototype ICN converter achieves a peak efficiency of 95.7% and maintains full-power efficiency above 91.7% across its 4:1 input voltage range. Compared to when operated under burst-mode control, the ICN converter with enhanced phase-shift control reduces converter losses by up to 30% and reduces the output capacitance requirement by two orders of magnitude.

**10:55AM***Soft-Switching Push-Pull Converter with Parallel Resonant Link and Buck-Boost Capability [#1017]*  
Morteza Moosavi and Hamid A. Toliyat   
, Texas A and M University, United States

A partial resonant push-pull converter with buck-boost capability is proposed. Magnetizing inductance of the three-winding transformer and three capacitors are used to form a parallel LC resonant link. The capacitors create a Zero Voltage Switching (ZVS) condition at turn-on and reduce the turn-off loss for all switches. Although the converter is not current-fed, there is no dc offset in the input current, thereby eliminating the saturation problem that is common to conventional push-pull converters. An analytical approach is developed to establish a relationship between link parameters, input and output voltages, and link frequency. Experimental results are included to corroborate the design and operation.

**11:20AM***Bidirectional Series-Resonant DC-DC Converter with Fault-Tolerance Capability for Smart Transformer [#801]*  
Levy Costa, Giampaolo Buticchi and Marco Liserre   
, University of Kiel, Germany

The Series-Resonant dc-dc converter (SRC) is widely used in several application and it became very popular in Smart Transformer application. In this application, fault tolerance is a highly desired feature and it is obtained through redundancy. This paper proposes a reconfiguration scheme for the SRC for the case of failure in one semiconductor, which could drastically reduce the need of redundancy. Using the proposed scheme, the full-bridge based SRC can be reconfigured in a half-bridge topology, in order to keep the converter operational even with the failure (open circuit or short circuit) of one switch. The theoretical analysis is carried out for the unidirectional SRC and then extended to the bidirectional topology, since bidirectionality is required in smart transformer application. To verify the feasibility of the proposed scheme, the converter is tested experimentally in a 700 V to 600 V prototype with 10 kW of output power. A IGBT short-circuit fault is tested and the results confirms the effectiveness of the proposed approach.

**11:45AM***Analysis and Design of Planar Inductor and Transformer for Resonant Converter [#432]*  
Yueshi Guan, Na Qi, Yijie Wang, Xiangjun Zhang, Dianguo Xu and Wei Wang   
, Harbin Institute of Technology, China

With the increasing demand of low-profile, high-power density for power electronics system, the planar magnetics (inductors and transformers) begin to be adopted in many fields. The copper tracks on printed circuit board (PCB) are mostly adopted as the windings of the planar magnetics which cannot be changed flexibly once the PCB is produced. So the design method of planar magnetics is an important issue. In this paper, the Response Surface Method (RSM) is adopted to design the planar inductor. The method can exactly obtain the inductance and resistance by the formulas obtained from experimental or simulation test results which can simplifying the design process. For the planar transformer, the Modular Layer Model (MLM) is adopted to build the final equivalent model of the transformer, by which the magnetizing inductance, leakage inductance and resistance can be calculated. The proposed design methods of planar inductor and planar transformer are verified by a resonant converter prototype.

Modeling and Control of Grid Connected Converter II

Thursday, September 22, 10:30AM-12:10PM, Room: 202D, Chair: Dragan Maksimovic, Matthias Preindl

**10:30AM***Combined DC Voltage Control Scheme for Three-port Energy Router Based on Instantaneous Energy Balance [#460]*  
Gaohui Feng, Zhengming Zhao, Liqiang Yuan and Kai Li   
, Tsinghua University, China

DC voltage control is crucial for the multi-stage converter, because it contributes to reduce the DC capacitance and improve the reliability of the whole system. A combined control scheme, including two parts, is proposed in this paper for controlling the two DC bus voltages respectively in the Energy Router. Firstly, the energy feed-forward control scheme is used to control the low voltage DC bus, which connects the dual active bridge, the inverter and the bidirectional DC/DC converter. Compared with the conventional feed-forward control scheme, the energy feed-forward control scheme considers the instantaneous energy changes of the inductors in the inverter and the DC/DC converter together. Secondly, for the high voltage DC bus, which is connected to the single-phase PWM rectifier, a new control scheme is proposed based on the energy balance relationship among the source, the load and the passive elements (the inductors and the capacitors). The proposed combined control scheme can improve obviously the transient performances of the two DC bus voltages. Simulation and experimental results have confirmed their superior performances.

**10:55AM***Grid-Voltage Sensorless Control of a Converter Under Unbalanced Conditions: On the Design of a State Observer [#180]*  
Jarno Kukkola and Marko Hinkkanen   
, Aalto University, Finland

This paper deals with grid-voltage sensorless synchronization and control under unbalanced grid conditions. A three-phase grid-connected converter equipped with an LCL filter is considered, and no other signals than the converter currents and the DC-link voltage are measured for control. An augmented adaptive state observer is proposed for estimation of the positive- and negative-sequence components of the grid voltage. The proposed observer is tested as a part of a sensorless control system. Experimental results show that the proposed method works well even in highly unbalanced grid conditions.

**11:20AM***Current-Mode Boundary Controller with Reduced Number of Current Sensors for a Three-Phase Inverter [#527]*  
He Yuanbin, Chung Shu-hung, Ho Ngai-man and Wu Weimin   
, City University of Hong Kong, Hong Kong; University of Manitoba, Canada; Shanghai Maritime University, China

Cascaded boundary-deadbeat controller has been proven to be effective in controlling single-phase grid-connected inverter with LCL output filter. Such architecture mitigates filter resonance and offers good stability under stiff and weak grid conditions. However, its merits are offset by requiring many sensors and high-precision intra-cycle information of the circuit variables to dictate the states of the switches. Moreover, the system will also be in variable switching frequency operation, due to coupling circuit variables amongst phases, in controlling three-phase three-wire inverter. This paper presents a boundary controller that utilizes second-order switching surface to track directly the output current of the three-phase three-wire grid-connected inverter with an LCL filter. By applying the 60-degree discontinuous pulsewidth modulation scheme for a fictitious decoupled dual-buck structure in each operation sector, two separate sets of switching criteria with reduced number of current sensors, fixed frequency operation and recovered intra-cycle information of circuit variables for dictating the states of the switches of two half-bridge legs are formulated. A 3kW, 127V/50Hz prototype is built to validate the effectiveness of the proposed control method.

**11:45AM***Positive- and Negative-Sequence Current Controller for Grid-Tied Converters With LCL Filters [#575]*  
Diego Perez-Estevez, Jesus Doval-Gandoy, Alejandro Yepes, Oscar Lopez and Fernando Baneira   
, University of Vigo, Spain

Traditionally, the current control of grid-tied converters with LCL filter is based on proportional-resonant or proportional-integral controllers, which often need an additional active damping method to achieve stability. These solutions do not permit to place the closed-loop poles in convenient locations when dealing with such high-order plants. This constraint results in degraded reference-tracking and disturbance-rejection responses. On the other hand, the existing methods based on direct pole placement or other modern control strategies, do not control with zero steady-state error both positive and negative sequences of the grid current, but only the positive one. This limitation is undesirable under unbalanced grid conditions. This paper presents a current controller for grid-tied converters with LCL filters based on direct discrete-time pole placement. The proposed controller makes it possible to control both positive and negative sequences of the grid-side current with zero steady-state error. Contrarily to the classical resonant controllers, the closed-loop poles can be placed in convenient locations, yielding a fast response with negligible overshoot and low controller effort. Moreover, no additional damping methods of the resonance are necessary to achieve stable operation, regardless of the switching frequency and LCL filter used. Simulation and experimental results that validate the proposal are presented.

Power Quality II

Thursday, September 22, 10:30AM-12:10PM, Room: 101B, Chair: Luca Solero, Maurizio Cirrincione

**10:30AM***Realization of Quadrature Signal Generator Using Accurate Magnitude Integrator [#1067]*  
Zhen Xin, Changwoo Yoon, Rende Zhao, Poh Chiang Loh and Frede Blaabjerg   
, Aalborg University, Denmark; China University of Petroleum (Hua dong), China

Second-Order Generalized Integrator based Quadrature Signal Generator (SOGI-QSG) has been widely used in single- or three-phase power converter systems due to its simplicity and flexibility. However, its dynamic response is not only decided by its damping gain but also influenced by the input-signal parameters, especially when a fast response is required for usages such as grid synchronization. As a result, the parameter design of the SOGI-QSG becomes complicated. Theoretical analysis shows that it is caused by the inaccurate magnitude-integration characteristic of the SOGI-QSG. To solve this problem, an Accurate-Magnitude-Integrator based QSG (AMI- QSG) is proposed. The AMI has an accurate magnitude-integration characteristic for the sinusoidal signal, which makes the AMI-QSG possess an accurate First-Order- System (FOS) characteristic in terms of magnitude than the SOGI-QSG. The parameter design process of the AMI-QSG can thus be as simple as the typical FOS. Besides, the structure of the AMI-QSG is further configured to be able to extract the dc component and harmonic components. The effectiveness of the proposed structures and the correctness of the theoretical analysis are evaluated by experimental results.

**10:55AM***A New Instantaneous Point on Wave Voltage Sag Detection Algorithm and Validation [#243]*  
Yujia Cui, Ahmed Sayed-Ahmed, Prathamesh Vadhavkar, Brian Seibel and Russel Kerkman   
, Rockwell Automation, United States

In industrial applications, power quality has been an issue drawing increasing concerns due to its severe consequences on system performance and downtime cost. Voltage sags are classified as one of the most common power quality issues. In order to guarantee system operation under several line sag scenarios, international standards such as SEMI F47, IEC-61000-4-34, and IEC- 61000-4-11 have been established as guidelines for electrical/electronics manufacturers. In this paper, an innovative point on wave sag detection is introduced. Although the main focus of this work is centered on applications related to regenerative motor-drive systems, this approach can be utilized in a myriad of other applications such as grid-tie inverters, uninterrupted power supplies and advanced relay protection. In addition, the introduced technique is very effective at detecting repeated line sag conditions. The introduced detection method has been experimentally validated using a 20 HP regenerative motor-drive system setup under various line sag scenarios.

**11:20AM***Voltage Quality Enhancement with Minimum Power Injection [#1203]*  
Darlan Fernandes, Fabiano Costa, Joao Martins, Alberto Lock, Edison da Silva and Montie Vitorino   
, Federal University of Paraiba, Brazil; Federal University of Bahia, Brazil; Federal University of Campina Grande, Brazil

This work proposes the usage of a repetitive-based control to dynamically restore the voltage applied to sensitive and critical loads of power systems. Besides, sag and voltage swells, the proposed control can intrinsically mitigate harmonic distortions. Furthermore, the filter is able to work out on sinusoid references and, thus, avoids the need of employing the dq transform. A recursive least-squares is also included to the control system in order to assure the synchronization of the injected voltages to be restored. The design of the control parameters along with the system stability are discussed throughout the paper. Also, this work aims to analyze two different types of voltage insertion into the grid through the series compensator. In the first one, the voltage injection is in synchronization with the pre-faulted grid voltage, while the second injects the voltage in a manner that the compensator spends a minimum of active power. Both types produce reference voltages that are used by the repetitive control. Additionally, simulated and experimental results are presented and corroborate the method efficacy.

**11:45AM***A Universal Variable On-time Compensation to improve THD of High-frequency CRM Boost PFC Converter [#896]*  
Zhehui Guo, Xiaoyong Ren, Handong Gui, Yu Wu, Zhiliang Zhang and Qianhong Chen   
, Nanjing Univ. of Aeronautics and Astronautics, China; The University of Tennessee, United States

The critical conduction mode Boost PFC converter utilizes the resonance to achieve soft-switching, however, leading to high THD and poor power quality, especially at high switching frequency applications. This paper presents a systematic operation analysis of the CRM Boost PFC converter considering the parasitic parameters and investigates the negative influence of resonance process to THD. In order to improve input current THD, a variable on-time control method is proposed to keep the average inductor current following the intended sinusoidal input current. The proposed implementation combines the advantages of digital control and analog control, effectively decreasing the total cost of the system. And the proposed variable on-time compensation method is verified with the experimental results well.

Stability in Power Converters I

Thursday, September 22, 10:30AM-12:10PM, Room: 102E, Chair: Jian Sun, Andrea Formentini

**10:30AM***On Impedance Modeling of Single-Phase Voltage Source Converters [#1228]*  
Shahil Shah and Leila Parsa   
, Rensselaer Polytechnic Institute, United States

This paper explores modeling of ac-side impedance for grid-connected single- phase voltage source converters (VSC). It shows that the conventional impedance, in the form of one-dimensional transfer function, may not completely capture the linearized dynamics of the converter. Resonance analysis using such impedance may fail for oscillations involving multiple frequency components. This problem is addressed by extending the impedance concept and defining a two-dimensional admittance for single-phase VSC. This admittance, in the form of a two-by-two transfer matrix, accurately captures the frequency cross-coupling effect that plays a critical role in low- frequency oscillations. A new form of signal-flow graphs is also introduced to represent the linearized dynamics of the VSC. These graphs visually demonstrate: a) the flow of perturbations through converter, b) why the conventional impedance fails in completely capturing the converter dynamics, c) how the two-dimensional model better captures them, and d) how to extend the concept further to higher dimensions without repeating the modeling process. Proposed two-dimensional and the conventional one-dimensional impedance models are developed for a single-phase VSC and they are validated using detailed circuit simulations.

**10:55AM***Design Consideration of Volt-VAR Controllers in Distribution Systems with Multiple PV Inverters [#1617]*  
Mahsa Ghapandar Kashani, Yonghwan Cho and Subhashish Bhattacharya   
, North Carolina State University, United States

Advanced control techniques such as Volt-VAR Control (VVC) are required for integration of multiple distributed renewable energy, such as Photovoltaic (PV) resources, on an electric distribution system. However, undesired interactions have been observed among these Volt-VAR controlled PV inverters which leads to oscillation and instability of the system. In this paper, an analytical approach to study the stability of local voltage control in high PV penetrated distribution systems with advanced Volt-VAR control functions is employed. The transient of inverter Volt-VAR Control interactions and dynamics of the interconnected feed-back loops in the distribution circuits are investigated. It is shown analytically that the Grid impedances, droop slope, PI controller parameters, response time and delay time in the VVC are the main factors affecting the dynamic response of the system, and the absence of a standard selection criteria for inverter and controller parameters under different Grid impedances results in undesired potential interactions among the PV inverters and distribution power system.

**11:20AM***Extended Stable Boundary of LCL-Filtered Grid-Connected Inverter Based on Grid-Voltage Feedforward Control [#1673]*  
Minghui Lu, Zhen Xin, Xiongfei Wang, Remus Beres and Frede Blaabjerg   
, Aalborg University, Denmark, Denmark

For the LCL-filtered grid-connected inverter, it has been reported that the digital time delays will narrow the stable region of current control loop when the inverter- side current is used for implementing the feedback control. A sufficient stable condition is that the filter resonance frequency should be designed under one-sixth of sampling frequency. However, the low resonance frequency leads to a comparatively large filter inductance or/and capacitance. To extend the stable boundary to the region above fs/6, this paper proposes a novel voltage feedforward scheme for the LCL- filtered inverter. Theoretical analysis is then provided to validate its feasibility and stability. Compared to other widely used active damping strategies, no extra sensors are needed because the filter capacitor voltage, which is used for voltage feedforward control, is also sampled for phase-locked loop in this paper. Simulations and experimental results are provided for verifying the theoretical analyses.

**11:45AM***Allowable Bus Impedance Region for MVDC Distribution Systems and Stabilizing Controller Design Using Positive Feed-Forward Control [#1266]*  
Jonathan Siegers, Silvia Arrua and Enrico Santi   
, University of South Carolina, United States

Advances in switching power electronic converter technology have brought about a resurgence of interest in the use of DC power distribution systems for a variety of applications. However, the notional power electronic based DC distribution system is a complex and extensively interconnected system consisting of multiple power converters. A number of system-level challenges related to stability arise due to interaction among multiple converter subsystems. The recently proposed Passivity Based Stability Criterion (PBSC) coupled with active damping by a Positive Feed-Forward (PFF) control technique has successfully been demonstrated to provide meaningful stability analysis and stabilizing controller design via the insertion of active damping impedances. However, the PBSC provides no explicit indication of the relative stability and damping of the system under study. This paper establishes an Allowable Impedance Region concept in the s-plane to relate the magnitude of the system bus impedance Nyquist contour to the expected dynamic performance of the system. This analysis technique provides information such that an appropriate damping impedance for insertion into the system bus via PFF control may be easily identified, thus ensuring the passivity of the system and guaranteeing stability and desired dynamic performance.

Non-Conventional Machine Configurations I

Thursday, September 22, 10:30AM-12:10PM, Room: 101A, Chair: Robert D. Lorenz, Ronghai Qu

**10:30AM***A Novel Stator-Consequent-Pole Memory Machine [#1030]*  
Yang Hui, Lin Heyun, Zhu Z. Q., Fang Shuhua and Huang Yunkai   
, Southeast University, China; University of Sheffield, United Kingdom

This paper proposes a novel stator-consequent-pole memory machine (SCPMM), in which the AlNiCo permanent magnets (PMs) with low-coercive-force (LCF) are alternately placed between the adjacent stator teeth. This new machine has the merits of simplified online PM magnetization, robust rotor and easy thermal management. Meanwhile, the energy-efficient flux regulation can be achieved since the LCF magnets can be repetitively magnetized or demagnetized with negligible excitation loss. The parallel magnetic circuit topology between PM and armature reaction fields permits the LCF PMs to well resist the irreversible demagnetization risk. In addition, the SCPMM benefits from the ease of manufacture since the stator and rotor assemblies are similar to the switched reluctance machines. Afterwards, the machine configuration and operating principle are introduced, respectively. The available slot/pole combinations are analyzed. The electromagnetic performances of the SCPMMs having various slot/pole combinations are investigated and compared. A prototype is manufactured and tested to experimentally validate the finite-element (FE) analysis.

**10:55AM***A Novel Variable Flux Memory Machine with Series Hybrid Magnets [#239]*  
Hao Hua, Z.Q. Zhu, Adam Pride, Rajesh Deodhar and Toshinori Sasaki   
, University of Sheffield, United Kingdom; IMRA Europe SAS, UK Research Centre, United Kingdom

This paper proposes a novel variable flux memory (VFM) machine, in which the constant permanent magnet (PM) (CPM) with high coercive force and the variable PM (VPM) with low coercive force are alternatively located in the interior-PM (IPM) rotor. Thus, the VPMs and CPMs are magnetically connected in series, with which the CPMs can assist the VPMs to withstand the unintentional demagnetization caused by armature reaction. Therefore, a high armature current can be applied to the machine. Meanwhile, the reluctance torque is retrieved. Thus, a high torque density can be obtained. The demagnetization and re-magnetization characteristics are investigated, in which the working points of VPMs are illustrated. Furthermore, the advantages of improved efficiency of the proposed VFM machine are demonstrated. A prototype machine is manufactured and tested to validate the predictions.

**11:20AM***On the Feasibility of Carbon Nanotube Windings for Electrical Machines - Case Study for a Coreless Axial Flux Motor [#1679]*  
Vandana Rallabandi, Narges Taran, Dan M. Ionel and John F. Eastham   
, University of Kentucky, United States; University of Bath, United Kingdom

The latest developments in carbon nanotube (CNT) wires and yarns attract great interest for potential application to electromagnetic devices, such as electrical machines and transformers. The CNT material properties are largely different from copper and aluminum in terms of electrical conductivity, mass density, and thermal transfer, creating a new design paradigm for which the traditional rules and device topologies no longer apply. This paper proposes a brushless permanent magnet multidisc axial flux construction with coreless stator and special windings and minimal rotor back iron, as a suitable topology for CNT winding application. Specific analytical closed-form sizing equations, as a function of winding electric conductivity, machine dimensions, and operating speed/frequency, are derived and employed in a systematic comparative study over a range of kW power ratings and speeds between 1,000 and 10,000 rpm. The numerical study is complemented by 3D and 2D electromagnetic FEA. The results show that the designs with CNT windings may have substantially higher specific power per mass, particularly at high rotational speeds and/or supply frequency, where the combined effect of DC and AC conduction losses in the windings is significant.

**11:45AM***A Novel Simplified Structure for Single-Drive Bearingless Motor [#827]*  
Hiroya Sugimoto, Itsuki Shimura and Akira Chiba   
, Tokyo Institute of Technology, Japan

This paper presents a novel design of simplified structure in one-axis actively positioned bearingless motor. To enhance torque density, while having extreme high passive stiffness, simple and compact structures are designed. Basic principle of active axial force generation and the calculated results in 3D-FEM analysis are presented. The axial force, torque and passive stiffness are compared in five structures. In addition, a minimization method of an interference torque and force is presented.

Noise and Vibration Issues in Electric Machines

Thursday, September 22, 10:30AM-12:10PM, Room: 102B, Chair: Junichi Itoh, Ali Bazzi

**10:30AM***Stator Vibration and Acoustic Noise Analysis of FSPM for a Low-Noise Design [#1586]*  
Chandan Sikder and Iqbal Husain   
, NC State University, United States

Noise and vibration in FSPM machines is one of the issues where improvement is needed, especially in topologies that are of segmented stator type. The stator mode frequencies and intensity of acoustic noise generated by magnetic radial force is related to the geometry, configuration and material properties. A method for estimating mode frequencies for segmented stator is proposed. A new pole shaping method is proposed to reduce the effect of undesirable mode frequencies on noise and vibration. The mode frequencies have been calculated using analytical models and verified using structural FEA. A low-noise FSPM design technique is proposed based on pole shaping and structural analysis. The effect of the proposed method on electromagnetic performance of the machine has also been investigated. A prototype FSPM is fabricated and tested based on the proposed design.

**10:55AM***Current Waveform for Noise Reduction of Switched Reluctance Motor in Magnetically Saturated Condition [#332]*  
Jihad Furqani, Masachika Kawa, Kyohei Kiyota and Akira Chiba   
, Tokyo Institute of Technology, Indonesia; Tokyo Institute of Technology, Japan

Permanent magnet motor are widely used in electric vehicle application. Advantages of permanent magnet motors are high efficiency and high torque density as well as low acoustic noise. However, permanent magnet motors have a disadvantage of a requirement of rare-earth materials. Rare-earth materials have cost fluctuation and this becomes major problem in electric and hybrid vehicles for mass production. One of the solutions for this problem is rare-earth-free motor. One of the possible motor types is a switched reluctance motor. Advantages of switched reluctance motors are low manufacturing cost, high reliability, robustness, possible operation at high temperature, and high rotational speed. Switched reluctance motors were considered to have disadvantages of low torque, low power density, low efficiency, high acoustic noise and vibration, and uncommon inverter circuit. A part of the authors have shown that a switched reluctance motor is competitive in torque density, efficiency, and power density compared with the permanent magnet motor employed in the leading hybrid electric vehicles. Acoustic noise and vibration is now the major problem to be solved in switched reluctance motors. In this paper, a novel method is proposed to derive the current waveform reduce noise and vibration of a switched reluctance motor in magnetically saturated region. Principle of noise and vibration reduction is based on reducing the variation of the radial force sum. To realize the minimum variation in the sum of radial forces, radial force expression for each phase should be derived. Radial force expression is approximated with Fourier series. With the proper approximation of radial force, the current waveform is derived to minimize the variation of the radial force sum. The proposed current waveform is consist of DC, fundamental, second, and third harmonic components. Finite element analysis and experiment result are included to show the validity of the proposed method.

**11:20AM***Torque Ripple Reduction Techniques for Stator DC Winding Excited Vernier Reluctance Machines [#640]*  
Mengxuan Lin, Ronghai Qu, Jian Li, Shaofeng Jia and Yang Lu   
, Huazhong University of Science and Technology, China

Stator DC winding Excited Vernier Reluctance Machines (DC-VRMs) are a kind of novel machines, which are investigated more and more owing to absence of expensive permanent magnet material. However, DC-VRMs are found to have large torque ripple if they are not carefully designed. There are a lot of existing methods to reduce the cogging torque in permanent magnet (PM) machines, but the design techniques for DC-VRMs have only been mentioned recently in few papers. In this paper, some new methods are proposed including shifted rotor tooth, stepped rotor skewing with multiple modules, T-shape rotor tooth, various rotor tooth arc, rotor tooth- chamfering, different length of air gap, and these methods are based on the techniques for PM machines to reduce torque ripple. The influence of the proposed methods on torque ripple is examined by using Finite Element Analysis (FEA) and it is found that the torque ripple can be reduced significantly.

**11:45AM***On the cross coupling effects in structural response of Switched Reluctance Motor Drives [#559]*  
Shiliang Wang, Lei Gu, Babak Fahimi and Mehdi Moallem   
, University of Texas at Dallas, United States; Isfahan University of Technology, Iran

Vibration and acoustic noise in switched reluctance motor (SRM) drives have been studied by many researchers. However, most of studies are related to vibration in the stator of SRM caused by radial forces acting on the stator itself. In this paper, a complete vibration analysis for a SRM assembly is conducted which considers the stator and rotor vibrations caused by electromagnetic forces as well as mechanical coupling between stator and rotor. Acceleration in the stator and rotor are computed using impulse response method under hysteresis current excitation. Our investigation illustrates a coupling between stator and rotor and its impact on the overall structural response of the machine.

Electrical Drives for Aerospace and Traction Applications

Thursday, September 22, 10:30AM-12:10PM, Room: 101CD, Chair: Gianmario Pellegrino, Davide Barater

**10:30AM***Asymmetrical Twelve-Phase Induction Starter/Generator for More Electric Engine in Aircraft [#902]*  
Radu Bojoi, Sandro Rubino, Andrea Cavagnino and Silvio Vaschetto   
, Politecnico di Torino, Italy

In this paper, a 12-phase asymmetrical induction machine is proposed as embedded starter/alternator connected to the high-pressure shaft of an open rotor jet engine. The main focus of the paper is on the modeling and control of the multiphase machine in order to verify its operation, including overload capabilities and post fault operations. The machine control uses a direct flux vector control scheme based on a multi-three-phase approach, where each three-phase winding set is independently controlled. In this way, the fault tolerant behavior of the drive system is improved. The proposed solution has been experimentally validated with a multi-modular power converter and a reduced scaled machine prototype (10 kW, 6000 rpm). The overload capability has been verified in generation mode for different speed values and torque up to the 150% the rated value. The sudden transition between healthy and faulty modes is reported for open-phases fault.

**10:55AM***Axial Position Estimation of Conical Shaped Motor for Green Taxiing Application [#1540]*  
Sara Roggia, Francesco Cupertino, Michael Galea and Chris Gerada   
, University of Nottigham, United Kingdom; Politecnico di Bari, Italy

This paper considers the possibility of adopting a conical shaped motor for Green Taxiing application. This topology of motor has been selected in order to obviate the presence of external declutching system interposed between the electric actuator and the wheel. An axial force contributes to move the rotor inside-out of the stator. The axial movement of the rotor can be monitored acting on the magnetizing current. The axial sensor-less position estimation method described hereafter envisages the possibility of evaluating the axial position of the rotor during the engaging and disengaging movement from the wheel. The axial position calculation is dependent on the inductance of the motor. An on-line computation of the position has been implemented through the use of high-frequency injection signals.

**11:20AM***Closed-form approach for predicting overvoltage transients in cable-fed PWM motor drives for MEA [#609]*  
Giorgio Pietrini, Davide Barater, Carlo Concari, Michael Galea and Chris Gerada   
, University of Parma, Italy; The University of Nottingham, United Kingdom

The More Electric Aircraft (MEA) concept has set tight constraints for power density and efficiency of electromechanical actuators in aircraft applications. In order to comply with these high power standards, new wide- bandgap (SiC and GaN) semiconductor devices may be exploited. Unfortunately, the extremely short switching times of these devices can easily trigger high frequency ringing voltage at motor terminal in cable-fed PWM motor drives due to pulse reflection. The resultant overvoltage stresses the insulation of stator windings decreasing the motor's lifespan. The most common solutions involve bulky and heavy passive filters, not suitable for MEA design approach, so the overvoltage suppression remains an open question. This paper explores the influence of pulse rising (and falling) time to the magnitude of motor terminal overvoltage through a detailed closed-form analysis of the problem in order to support electrical drive design optimization.

**11:45AM***An open problem for More Electrical Aircraft (MEA): how insulation systems of actuators can be qualified? [#445]*  
Giorgio Pietrini, Davide Barater, Giovanni Franceschini, Paolo Mancinelli and Andrea Cavallini   
, University of Parma, Italy; University of Bologna, Italy

The concept of More Electric Aircraft (MEA) aims to address the demand for efficiency, reliability and maintainability of today aerospace industry by means of an in-depth electrification of the currently hydraulic, mechanical and pneumatic on-board actuators. The high power density of electric actuators shall decrease substantially the aircraft weight as well as its fuel consumption and environmental impact. However, safety and reliability are primary drivers of this sector. This paper will review the main stress factors affecting the lifespan of insulation materials used in aerospace actuators, concentrating in particular to the influence of the low atmospheric pressure at high altitude and to the effect of wide band-gap power devices' short rise times on voltage stress in windings.

Magnetics II

Thursday, September 22, 10:30AM-12:10PM, Room: 102A, Chair: Shuo Wang, Gerard Hurley

**10:30AM***High Power Density Impedance Control Network DC-DC Converter Utilizing an Integrated Magnetic Structure [#1428]*  
Ashish Kumar, Jie Lu, Saad Pervaiz, Alihossein Sepahvand and Khurram Afridi   
, University of Colorado Boulder, United States

This paper introduces a high-power-density high-efficiency isolated dc-dc converter based on the impedance control network (ICN) resonant converter architecture. The ICN converter maintains very high efficiency by achieving zero voltage switching (ZVS) and near zero current switching (ZCS) across a wide range of input voltages, output voltages and output power. High power density is achieved by combining the three inductors of the ICN converter into a single integrated magnetic structure with two coupled windings. Power losses in this integrated magnetic structure are minimized using a finite element analysis (FEA) based design optimization approach. A prototype 550-W, 1-MHz ICN converter incorporating the integrated magnetic structure, designed to operate over an input voltage range of 36 V to 60 V and an output voltage range of 34 V to 55 V is built and tested. The prototyped ICN converter achieves a power density of 462 W/in3, a peak efficiency of 96.7% and maintains efficiencies above 94.8% across its entire operating range.

**10:55AM***Time-Domain Homogenization of Litz-Wire Bundles in FE Calculations [#1388]*  
Korawich Niyomsatian, Jeroen Van den Keybus, Ruth Sabariego and Johan Gyselinck   
, Triphase, ULB, Belgium; Triphase, Belgium; KU Leuven, Belgium; ULB, Belgium

This paper deals with a time-domain homogenization technique for litz-wire bundles embedded in a finite element (FE) model. An elementary FE model is used to determine dimensionless frequency- and time-domain coefficients regarding the skin and proximity effects in litz-wire bundles. Thanks to these coefficients, litz-wire bundles become homogeneous conductors which are easy to integrate into a FE model of a complete device. The method is validated with the reference solution of the 2-D FE transformer model, which is computed by finely discretizing each conductor. The results agree well with the accurate reference solution.

**11:20AM***High Frequency Core Coefficient for Transformer Size Selection [#98]*  
Lukas Mueller and Jonathan Kimball   
, Missouri University of Science and Technology, United States

Transformer design is critical as the demands on power converter efficiency and power density increase. Initial transformer core shape and size selection can be challenging, in many cases necessitating multiple elaborate design iterations to find a suitable core. A number of core constants have been proposed in the past to assist with initial core selection, however, most of them do not consider high frequency losses in transformer cores which are becoming increasingly important. The Kgfe transformer design method is adapted in this paper to consider high frequency copper losses in transformer designs with bi-directional excitation and two windings. The presented expressions can be used to quickly determine the minimum achievable power losses for a given core size, material and wire diameter.

**11:45AM***Very High Frequency Integrated Voltage Regulator for Small Portable Devices [#1403]*  
Dongbin Hou, Fred Lee and Qiang Li   
, CPES, Virginia Tech, United States

As small portable devices (smartphones, tablets, etc.) becomes lighter, thinner, quicker, and smarter, the voltage regulator for the processor is expected to be efficient, miniaturized, integrated, and placed closer to the processor. In this paper, a concept of very high frequency (tens of MHz) 3D integrated voltage regulator for small portable devices is proposed. Both single-phase and 5-phase integrated inductor with NEC flake magnetic material is designed, fabricated and experimentally tested at 20MHz, featuring simple single-via winding structure, small size, ultra-low profile, ultra-low DCR, air-gap-free magnetic core, and lateral non-uniform flux.

Device Short Circuit Capability

Thursday, September 22, 10:30AM-12:10PM, Room: 202C, Chair: Yi Deng, Ty McNutt

**10:30AM***Robustness in Short-Circuit Mode: Benchmarking of 600V GaN HEMTs with Power Si and SiC MOSFETs [#791]*  
Nasser Badawi, Abdullah Eial Awwad and Sibylle Dieckerhoff   
, Technical University of Berlin, Germany

A short circuit e.g. in a half-bridge converter is a severe and potentially destructive operation condition for a power transistor and needs to be turned off quickly and safely. In order to define strategies how to improve the reliability of a power device, it is necessary to understand the failure dynamics during a short-circuit. In this paper, an experimental study focussing on the short-circuit capability of different types of 600V power transistors based on Si, SiC and GaN is presented. Usually, a 10 microseconds short-circuit withstand time at 400V is required for 600V power transistors. Measurement results show that the investigated Si and SiC MOSFETs can withstand short circuit times up to 13 microseconds at 400V and 150 degree, while the normally-off and cascode GaN devices demonstrate considerably less withstand capability. demonstrate considerably less withstand capability.

**10:55AM***Investigation on the Short Circuit Safe Operation Area of SiC MOSFET Power Modules [#554]*  
Paula Diaz Reigosa, Francesco Iannuzzo, Haoze Luo and Frede Blaabjerg   
, Aalborg university, Denmark; Aalborg University, Denmark

This paper gives a better insight of the short circuit capability of state-of-the-art SiC MOSFET power modules rated at 1.2 kV by highlighting the physical limits under different operating conditions. Two different failure mechanisms have been identified, both reducing the short-circuit capability of SiC power modules in respect to discrete SiC devices. Based on such failure mechanisms, two short circuit criteria (i.e., short circuit currentbased criterion and gate voltage-based criterion) are proposed in order to ensure their robustness under short-circuit conditions. A Safe Operation Area (SCSOA) of the studied SiC MOSFET power modules is formulated based on the two proposed criteria.

**11:20AM***Short-Circuit Protection of 1200V SiC MOSFET T-type Module in PV Inverter Application [#499]*  
Yuxiang Shi, Ren Xie, Lu Wang, Yanjun Shi and Hui Li   
, FSU, United States

A de-sat based short-circuit protection scheme using commercial driver for SiC MOSFETs is presented and experimentally verified on 1200V 3-level T-type SiC MOSFET module in this paper. Response time is very critical for the short circuit protection of SiC MOSFETs due to the limited short circuit withstand time (SCWT). Soft turn-off is required to avoid high voltage spike during the turn-off of the fault current. With the presented circuit, 600 ns response time is realized, and a two stage soft turn-off circuit with gate voltage clamping is implemented. A gate voltage stabilizing circuit without affecting the switching loss is also proposed to prevent false trigger. Since de-sat protection scheme is not applicable for the neutral branch of T-type module due to polarity changes of branch voltage, the short-circuit protection of neutral branch is realized with the half-bridge device protection. Detail circuit design for the 1200 V T-type SiC module in 1 kV PV application is described, and experimental results demonstrate the effectiveness of the circuit.

**11:45AM***Prediction of Short-Circuit-Related Thermal Stress in Aged IGBT Modules [#1037]*  
Amir Sajjad Bahman, Francesco Iannuzzo, Christian Uhrenfeldt, Frede Blaabjerg and Stig Munk-Nielsen   
, Aalborg University, Denmark

In this paper, the thermal stress on bond wires of aged IGBT modules under short-circuit conditions has been studied with respect to different solder delamination levels. To ensure repeatable test conditions, ad-hoc DBC (direct bond copper) samples with delaminated solder layers have been purposely fabricated. The temperature distribution produced by such abnormal conditions has been modelled first by means of FEM simulations and then experimentally validated by means of a non-destructive testing technique including an ultra- fast infrared camera. Results demonstrate a significant imbalance in the surface temperature distribution which confirms the hypothesis that short- circuit events produce significantly uneven stresses on bond wires.

Thursday, September 22, 2:00PM-3:40PM

DFIG Based Wind Power Systems

Thursday, September 22, 2:00PM-3:40PM, Room: 203AB, Chair: Wei Qiao, Behrooz Mirafzal

**2:00PM***Flexible PCC Voltage Unbalance Compensation Strategy for Autonomous Operation of Parallel DFIGs [#59]*  
Tao Wang and Heng Nian   
, Zhejiang University, China

This paper proposes a flexible compensation strategy for parallel-connected doubly fed induction generators (DFIGs) when connected to an unbalanced weak grid. The proposed strategy has two main advantages: 1) the voltage unbalance factor (VUF) at the point of common coupling (PCC) can be continuously controlled, thus the flexible trade-off between the balanced DFIG output current and the balanced PCC voltage can be achieved; 2) the negative sequence current required by the compensation can be accurately shared among the parallel DFIG systems according to their respective operation conditions without the need of real-time communication. The proposed strategy is introduced in detail and simulation results are carried out to verify the proposed compensation strategy.

**2:25PM***Analysis and Comparison of Super- Synchronous Resonance in Small and Large Scale DFIG System [#187]*  
Yipeng Song, Frede Blaabjerg and Xiongfei Wang   
, Aalborg University, Denmark

When connected to a parallel compensated weak grid network, both the small and large power scale Doubly Fed Induction Generator (DFIG) system may suffer high frequency resonance (HFR) due to the impedance interaction between the DFIG system and the parallel compensated weak network. Since the parameters of the small and large scale DFIG systems, including DFIG machine parameters and the LCL filter parameters, may vary between 10 to 100 times, the impedance modeling results of small and large scale DFIG system are quite different. Based on the built impedance modeling results, the HFR in small and large scale DFIG system are theoretically analyzed and compared in this paper with the discussion on the influence of PI controller proportional parameters and the digital control delay on the DFIG system impedance shaping. The experimental validation of small scale DFIG system and the simulation validation of large scale DFIG system are conducted to verify the correctness of the analysis.

**2:50PM***A Super-synchronous Doubly Fed Induction Generator Option for Wind Turbine Applications [#724]*  
Kee Shin and Thomas Lipo   
, ABB, United States; University of Wisconsin - Madison (WEMPEC), United States

Doubly fed induction generators are presently used in the large majority of high power wind turbine applications. The current doubly-fed induction generator technology specifies that the turbine operates sub-synchronously to follow the desired power vs. wind speed profile and to operate super- synchronously only during brief periods where wind gusts exceed the nominal maximum value of thrust. This paper suggests that improved operation is possible if the generator is confined to always operate in the super- synchronous state resulting in improved efficiency and greater output power, and the cost effective power converter arrangement and control scheme for the super-synchronous operation are proposed and investigated in this paper.

**3:15PM***Fault Diagnosis of Wind Turbine Gearbox Using DFIG Stator Current Analysis [#1289]*  
Fangzhou Cheng, Chun Wei, Liyan Qu and Wei Qiao   
, University of Nebraska-Lincoln, United States

Gearbox faults are a leading reliability issue in wind turbines. Generator current-based methods have been successfully used in gearbox fault diagnosis and have shown advantages over the traditional vibration-based techniques in terms of implementation, cost, and reliability. This paper proposed a new generator stator current-based fault diagnostic method for the gearboxes in doubly-fed induction generator (DFIG)-based wind turbines under varying rotating speed conditions. Hilbert transform is first used to demodulate the stator current signal, and then a Vold-Kalman filter is designed to separate the nonstationary fault-related components (called the faulty signal) from the demodulated nonstationary stator current signal. Next, a synchronous resampling algorithm is designed to convert the nonstationary faulty signal to a stationary signal. Finally, the power spectral density (PSD) analysis is applied to the resampled faulty signal for the gearbox fault diagnosis. Experimental results obtained from a DFIG wind turbine drivetrain test rig are provided to verify the effectiveness of the proposed method for gearbox fault diagnosis.

Utility Scale Battery Systems

Thursday, September 22, 2:00PM-3:40PM, Room: 203C, Chair: Daniel-Ioan Stroe, Frede Blaabjerg

**2:00PM***Controller for Combined Peak-Load Shaving and Capacity Firming Utilizing Multiple Energy Storage Units in a Microgrid [#147]*  
Andrew Hintz, Kaushik Rajashekara and Prasanna Rajagopal   
, The University of Texas at Dallas, United States

In this paper, a controller capable of simultaneously providing both peak-load shaving and capacity firming required by renewable energy sources is proposed. This controller is designed to combine power/energy from multiple energy storage systems, including unidirectional systems such as fuel cells. Quick response energy storage systems such as ultra capacitors meet the requirements of initial fluctuations in power, and slower response systems provide the power for extended periods of activity. The rate of response of each energy storage system is a parameter known to the control system. The proposed algorithm improves the overall system's performance in terms of fast response, smart energy management, and ability to manage different energy storage and unidirectional/bidirectional sources. Simulations verify the operation of the control strategy in peak shaving mode and in steady state mode that can extend for a longer duration. Results show preferential power allocation to the quick response energy storage system, and limited power fluctuations on other sources.

**2:25PM***Energy Storage Configuration Strategy for Virtual Synchronous Machine [#449]*  
Chang Yuan, Chang Liu, Tianyang Zhao, Niang Tang and Xiangning Xiao   
, North China Electric Power University, China; Electric Power Research Institute of Guangdong, China

This paper investigates energy storage configuration strategy for virtual synchronous machine (VSM). The proposed VSM provides virtual inertia and damping to maintain stability of grid. Virtual inertia and damping need to be established by energy storage system (ESS). So that a strategy of energy storage configuration has been investigated through theoretical analysis and simulations in this paper. In addition, this paper also proposed influences of virtual inertia, damping factor and reference of reactive power on energy storage configuration. Simulation results verified the proposed energy storage configuration strategy.

**2:50PM***Control of Energy Storage System integrating electrochemical batteries and SC for grid-connected applications [#964]*  
Ruben Capo-Misut, Raul Santiago Munoz-Aguilar, Joan Rocabert, Jose Ignacio Candela and Pedro Rodriguez   
, Universitat Politecnica de Catalunya, Spain; Abengoa Research S.L., Spain

Ancillary services offered by renewable energy sources frequently requires the capability of bidirectional power flow and power reserve, so an energy storage system (ESS) is a solution for this requirement. A large variety of ESS solutions are in the market, and frequently are mixed to optimize the global performance. This paper presents the integration of supercapacitors (SC) and electrochemical batteries for grid-supporting applications. The large operating voltage range of a SC requires a power conversion stage to adapt the energy stored into a common dc-bus composed by a battery bank. This is achieved through bidirectional dc-dc interleaved buck / boost converters feeding a common higher-voltage dc-bus, composed by the battery. In order to integrate the energy storage mix to the grid, through a grid-supporting inverter, a power control loop has been implemented with the goal of take advantage of the high dynamic performance of the SC bank and high reserve capacity of the battery system.

**3:15PM***A Novel Approach towards Energy Storage System Sizing Considering Battery Degradation [#1700]*  
Yuhua Du, Rishabh Jain and Srdjan M. Lukic   
, North Carolina State University, United States

Energy Storage System (ESS), with its fast ramping and bi-direction power flow capabilities, is playing a more vital role in the electric market. However, it still stands on the farther end of economic viability. As a result, a good estimate of battery service life, and therefore revenue, is necessary before the investment is made in any given application. In this paper, a set of improved degradation models are propose to estimate the useful life of an ESS when subjected to daily duty cycles (4-sec resolution). The models are validated and tuned for the target Li-Nickel Cobalt Aluminum Oxide (NCA) batteries. Time to End of Life (EOL) is estimated for batteries of different sizes to provide ancillary services and/or energy services in electric market, given different end-of-cycle state of charge. Finally, the strategies which can be used to size the battery for maximizing time to EOL are discussed.

AC Microgrids III: Operation, Control and Energy Management

Thursday, September 22, 2:00PM-3:40PM, Room: 203DE, Chair: Juan Carlos Vasquez, Juan Manuel Guerrero

**2:00PM***Robust Decentralized Voltage and Frequency Control of Generators in Islanded Microgrids Using $$-Synthesis [#1633]*  
Mohsen Azizi and Sayed Ali Khajehoddin   
, Michigan Technological University, United States; University of Alberta, Canada

In this paper, a robust decentralized controller is designed for automatic voltage regulator (AVR) and load frequency control (LFC) systems of a generator in an islanded microgrid with multiple distributed generation systems. This control strategy can be readily applied to an islanded microgrid which consists of renewable distributed generation and energy storage systems. The control strategy proposed in this paper includes multiple local droop controllers, as well as robust decentralized controller that are designed and optimized independently by using the $\mu$-synthesis technique. These controllers account for the dynamic coupling among the areas of the islanded microgrid without any communication links required among the local controllers. Moreover, these controllers are designed to be robust to the variations of different parameters of the microgrid, and hence improve the voltage and frequency control performance significantly. Simulation results of a small microgrid with a generator and a renewable energy resource confirm the effectiveness of the controller design approach proposed in this paper.

**2:25PM***Thyristor Based Short Circuit Current Injection in Isolated Grids [#134]*  
Bjarte Hoff, Pawan Sharma and Trond Ostrem   
, UiT The Arctic University of Norway, Norway

This paper proposes a thyristor based short circuit current injector for providing short circuit current in isolated and weak grids, where sufficient fault current to trigger circuit breakers may not be available. This will allow the use of conventional miniature circuit breakers, which requires high fault current for instantaneous tripping. The method has been validated through experiments.

**2:50PM***Optimized Energy Management System to Reduce Fuel Consumption in Remote Military Microgrids [#613]*  
Norma Anglani, Michele Colombini and Giovanna Oriti   
, University of Pavia, Italy; Generac Mobile Products, Italy; Naval Postgraduate School, United States

This paper presents an optimized energy management system (OEMS) to control the microgrid of a remote temporary military base featuring the diesel generators, the battery energy storage system (BESS) and photovoltaic panels (PV). The information of the expected electric demand is suitably used to improve the sizing and management of the BESS. The OEMS includes power electronics to charge the batteries from either the PV source or the diesel generators, it can function as a current source when it is supplementing the power from one of the generators or as a voltage source when it is the sole source of power for the loads. The novelty in the overall optimization procedure lies (i) in using Special Ordered Sets (SOSs) for the semicontinuous function handling and (ii) in integrating economic evaluations, by properly taking into account how the size of BESS affects its charge/discharge cycle, thus the lifetime. Results from optimization are employed by the OEMS to coordinate the energy sources and match the critical and non critical loads with the available supply. Fuel savings of 30% (and 50% adding the PV source) can be achieved with respect to the already improved, but not optimal, solution of a previous work.

**3:15PM***Analysis and Improvement of the Energy Management of an Isolated Microgrid in Lencois Island based on a Linear Optimization Approach [#1118]*  
Federico de Bosio, Adriana Carolina Luna, Luiz Antonio de Souza Ribeiro, Moises Graells, Osvaldo Ronald Saavedra and Josep Maria Guerrero   
, Politecnico di Torino, Italy; Aalborg University, Denmark; Federal University of Maranhao, Brazil; Universitat Politecnica de Catalunya, Spain

This paper proposes an optimization-based decision support strategy to enhance the management of the distributed energy sources of an islanded microgrid. The solutions provided by the optimization algorithm are compared with the current strategy, already implemented in a real site microgrid on Lencois' island/Brazil. Significant economic and energy savings are achieved when the optimal management of the diesel generator is performed.

Battery Charging for Transportation Electrification

Thursday, September 22, 2:00PM-3:40PM, Room: 102D, Chair: Theodore Bohn, Alireza Khaligh

**2:00PM***A Primary Full-Integrated Active Filter Auxiliary Power Module in Electrified Vehicle Applications with Single-Phase Onboard Chargers [#12]*  
Ruoyu Hou and Ali Emadi   
, McMaster University, Canada

The active filter auxiliary power module (AFAPM) has been proposed for electrified vehicle applications with single-phase onboard chargers. It has two modes: 1) the high-voltage (HV) active filtering mode, in which the vehicle is connected to the grid and the converter assimilates the significant second-order harmonic current introduced by the single-phase power; 2) the low-voltage (LV) battery charging mode, in which the vehicle is running and the converter charges the LV battery from HV battery. This yields a significant capacitance reduction on the DC-link of HV battery charger without an additional active filter (AF) circuit. However, extra relay and inductors are needed. This paper proposes a primary full integrated AFAPM, which is composed of a two-phase buck converter to work as an AF and a dual-active-bridge (DAB) to operate as a LV battery charger auxiliary power module (APM). With the proposed converter, only an active energy storage capacitor is needed to achieve the active filtering and store the second-order harmonic energy. All the switches and inductors on the primary stage are shared between the AF and APM. Therefore, the cost and size of the dual-voltage charging system in the vehicle applications can be reduced further. To confirm the effectiveness of the proposed converter, a 720 W prototype has been built and experimental results are presented.

**2:25PM***Sensitivity Analysis of a Wireless Power Transfer (WPT) System for Electric Vehicle Application [#1404]*  
Madhu sudhan Chinthavali and Zhiqiang Wang   
, ORNL, United States

This paper presents a detailed parametric sensitivity analysis for a wireless power transfer (WPT) system in an electric vehicle application. Specifically, several key parameters for sensitivity analysis of a series-parallel (SP) WPT system are derived first based on analytical modeling approach, which includes the equivalent input impedance, active / reactive power, and DC voltage gain. Based on the derivation, the impact of primary side compensation capacitance, coupling coefficient, transformer leakage inductance, and different load conditions on the DC voltage gain curve and power curve are studied and analyzed. It is shown that the desired power can be achieved by just changing frequency or voltage depending on the design value of coupling coefficient. However, in some cases both have to be modified in order to achieve the required power transfer at high efficiencies.

**2:50PM***Design of a Dual-Loop Controller for In-motion Wireless Charging of an Electric Bus [#1426]*  
Reza Tavakoli, Aleksandar Jovicic, Niranjan Chandrappa, Ryan Bohm and Zeljko Pantic   
, Utah State University, United States

In this paper, a 25-kW Wireless Power Transfer (WPT) system is considered for in-motion charging of an electric bus. The goal of this research is to derive a control strategy for the primary side of a wireless Electric Vehicle (EV) charger, with the objective to achieve fast dynamics and full control over the primary coil current and the amount of transferred power. To this aim, a dual-loop controller has been proposed which utilizes two feedback PI controllers combined with two feed-forward controllers to set targeted steady state operation points. Using Generalized State Space Averaging (GSSA) approach, the primary side of the wireless charger system is modeled. This includes full-bridge inverter, LCC compensation circuit and primary track or coil. By using this small-signal model, two closed loop digital PI controllers have been designed to ensure fast and accurate response of the track current controller, as well as control of the power flow transferred to the secondary side. In order to increase the reliability of the system, two feed-forward controllers have been added to the PI controllers. For the current controller (inner loop) the feed-forward controller is based on a sigmoid phase angle profile, and for the power controller (outer loop), it is derived based on an analytical equation relating transferred power and primary track current. The simulation and experimental results demonstrate expected operation of the entire control system for a typical load profile observable in in-motion charging applications.

**3:15PM***Design of CRM AC/DC Converter for Very High-Frequency High-Density WBG-Based 6.6kW Bidirectional On-Board Battery Charger [#1427]*  
Zhengyang Liu, Bin Li, Fred Lee and Qiang Li   
, CPES\_Virginia Tech, United States

The wide-band-gap (WBG) devices based 6.6 kW bidirectional on-board charger (OBC) system for plug-in electric vehicles (PEVs) is recently developed. With the proposed novel variable DC-link voltage system architecture, high frequency soft switching operation, and integrated magnetics, the OBC system becomes more compact and more efficient compared to a Si-based counterpart. The design considerations of the AC/DC stage are introduced in this paper including the evaluation of 1.2 kV SiC MOSFETs; the zero-voltage-switching (ZVS) extension function for the line-cycle ZVS operation; and the novel universal control strategy for both the rectifier mode and the inverter mode. The prototype of the AC/DC stage is built which achieves 98.5% efficiency at higher than 300 kHz switching frequency. Finally, the complete 6.6 kW OBC system using both SiC and GaN devices is demonstrated with 37 W/in3 power density and above 96% efficiency.

Three-Phase Inverter PWM

Thursday, September 22, 2:00PM-3:40PM, Room: 202A, Chair: Subhashish Bhattacharya, Giacomo Scelba

**2:00PM***SiC MOSFET Zero-Voltage-Switching SVM controlled Three-phase Grid Inverter [#558]*  
Ning He, Yawen Li, Chengrui Du, Chao Liu, Changsheng Hu and Dehong Xu   
, Zhejiang University, China, China

Although SiC-MOSFET has shown significant advantages on switching performance compared with traditional Si counterpart, the dynamic loss of the hard switching SiC-MOSFET converter rises quickly with the increasing of the switching frequency. To further pushing the power density of SiC-MOSFET gird inverter, soft switching inverter with Zero-Voltage-Switching (ZVS) SVM technique is investigated. In this paper the loss distributions and conversion efficiencies of both a 30kW hard switching inverter and a 30kW ZVS inverter with SiC MOSFET devices have been derived and compared with respect to physical size of the passive components with different switching frequencies from tens of kHz to hundreds of kHz. In order to evaluate the efficiency performance of different topologies with the increasing switching frequency, a new concept called Efficiency Endurance is proposed. Both the theoretical and experimental results have confirmed that the ZVS inverter is more advantageous in high switching frequency applications.

**2:25PM***A Novel Soft-switching Modulation Scheme for Isolated DC-to-three-phase-AC Matrix-based Converter Using SiC Device [#1268]*  
Xiaohang Yu, Fanning Jin and Mengqi Wang   
, University of Michigan-Dearborn, United States

This paper presents a novel unipolar SPWM-oriented modulation for the isolated bi-directional DC- to-three-phase-AC converter with high-frequency-link (HFL) using SiC MOSFETs. The converter consists of a full bridge (FB) stage and a single-to-three-phase matrix converter with high frequency transformer isolation. Under the proposed modulation, zero voltage switching (ZVS) is realized for the full bridge and zero voltage zero current switching (ZVZCS) is realized for the switches operating in the selected modes in the matrix converter for all load range. Synchronous Rectification (SR) is implemented for switches operating in the complimentary and synchronous modes. The proposed modulation technique takes advantages of the manifest merits of SiC devices such as the low turn- on resistance and ultra-fast reverse recovery characteristic. Moreover, the voltage spike induced by the transformer leakage inductance is mitigated with the proposed modulation technique without additional snubber circuits or components. The simulation results provided well validate the functionality and effectiveness of soft-switching of the proposed modulation. For the experimental results, the proposed modulation with SiC devices is implemented to improve the efficiency from 88.0% to 94.1% at 1.3kW compared to traditional modulation in matrix converter.

**2:50PM***New PWM Technique for Grid-Tie Isolated Bidirectional DC-AC Inverter Based High Frequency Transformer [#816]*  
Mahmoud Sayed, Suzuki Kazuma, Takeshita Takaharu and Kitagawa Wataru   
, Nagoya Institute of Technology, Japan

This paper presents a new PWM switching technique for controlling a bidirectional isolated DC-AC-AC inverter along with its soft-switching technique. The proposed PWM technique has the ability to control the input DC current and to inject a sinusoidal three-phase current to the grid at unity power factor. In the first stage, an H-bridge converter is used to convert the DC voltage to a high-frequency square-wave single-phase voltage. In the second stage, a matrix converter is used to convert the high- frequency voltage waveform to conventional three-phase voltage synchronized with the grid. Therefore, a high-frequency transformer is used to link the H-bridge output voltage to the matrix converter input voltage. The proposed soft-switching technique is achieved by connecting shunt capacitors across the DC-AC-AC converter switches. The mathematical model and the circuit operation for soft-switching are presented along with the voltage controllable limits. The effectiveness of the proposed technique has been verified experimentally using a laboratory prototype.

**3:15PM***Reduction of Input Current Harmonics based on Space Vector Modulation for Three-phase VSI with varied Power Factor [#318]*  
Koroku Nishizawa, Jun-ichi Itoh, Akihiro Odaka, Akio Toba and Hidetoshi Umida   
, Nagaoka University of Technology, Japan; Fuji Electric Co., Ltd., Japan

This paper proposes space vector modulation (SVM) which reduces the current harmonics flowing through the DC-link capacitor of three-phase motor drive systems. In a conventional SVM, the selection of the space vectors results in the long zero vector period, which increases the inverter input current harmonics. On the other hand, in the proposed SVM, the space vectors are selected in order to actively shorten the zero vector period. Furthermore, by applying the proposed SVM only in the regions where the instantaneous value of the input current is positive, the input current harmonics are reduced even when the load power factor becomes low. Through the experiment applying the proposed SVM, it is confirmed that input current harmonics is reduced by up to 33.9% of that of the conventional method. Moreover, it is confirmed that the input current harmonics with the proposed SVM are reduced in all range of the load power factor compared to that of the conventional SVM.

AC-AC Converters II

Thursday, September 22, 2:00PM-3:40PM, Room: 202E, Chair: Luca Zarri, Matthias Preindl

**2:00PM***A Comparison of Indirect Matrix Converter Based Open-End Winding Drives Against State-of-the-Art [#708]*  
Saurabh Tewari and Ned Mohan   
, MTS Systems Corporation, United States; University of Minnesota, United States

To choose between matrix converter based open-end winding drives and the state-of-the-art, the input/output waveform quality, passive component requirements, and the total losses of several different solutions are evaluated in this paper. Special attention has been paid to the output common-mode voltage related phenomenon since common-mode elimination is the primary motivation for employing modulation using rotating vectors and an open-end winding drive topology.

**2:25PM***Common Mode Voltage Reduction in Open-End Multi-phase Load System fed Through Matrix Converter [#909]*  
Khaliqur Rahman, Atif Iqbal, Nasser A. Al-Emadi, Rashid M Alammari, Lazhar Ben Brahim and Hossein Dehghani Tafti   
, Qatar University, Qatar; Nanyang Technological University, Singapore

In this paper reduction of common mode voltage (CMV) for five phases open end load system is discussed. Open end load is fed through three-to-five phases dual matrix converters (DMC). Space vector pulse width modulation (SVPWM) technique is used for the modulation of the DMC which is assumed to have two stages rectification and inversion. Their controls are separate and independent of each other. The rectifier output is considered as a fictitious DC voltage and an input for the inverter. The CMV is reduced by proper selection and placement of the active vectors in the inversion stage. The performance of the matrix converter is discussed. By an appropriate vector selection, the proposed technique is capable to reduce the CMV magnitude as well as the peak in the output of the open end load. Moreover, the input power factor remains unity and the voltage transfer ratio is increased up to 150% when compared with a simple three-to-five phases matrix converter (MC). The proposed technique is validated by simulation and experimental results.

**2:50PM***Experimental Comparison of Devices Thermal Cycling in Direct Matrix Converters (DMC) and Indirect Matrix Converters (IMC) using SiC MOSFETs [#99]*  
Andrew Trentin, Liliana de Lillo, Lee Empringham, Pericle Zanchetta, Pat Wheeler and Jon Clare   
, The University of Nottingham, United Kingdom

This paper presents an experimental comparison between a Direct Matrix Converter and an Indirect Matrix Converter in terms of semiconductor devices thermal cycling. Both converters have been designed and built using SiC MOSFETs; the Indirect Matrix Converter has also been tested using a hybrid solution with Silicon IGBT on the input stage and SiC MOSFETs on the output stage.

**3:15PM***A Carrier-based Modulation Strategy for Multi-modular Matrix Converters with Zero Common-mode Voltage [#394]*  
Wenjing Xiong, Yao Sun, Mei Su, Jian Yang and Chunsheng Wang   
, Central South University, China; Central South University, Jiangxi Kangcheng Co., China

This paper presents a carrier based modulation strategy for three modular matrix converters to achieve zero common mode voltage. A geometric method is introduced to determine the range of the modulation signals. Due to the nonzero common mode voltage during the commutation time with the traditional four step current based commutation method, a modified commutation method is presented. Additionally, to expand the modulation strategy to multimodular matrix converter properly, the phase shifted method is applied. The simulation results proved the correctness and effectiveness of the proposed modulation strategy.

Modular Multilevel Converters (MMC) III

Thursday, September 22, 2:00PM-3:40PM, Room: 202B, Chair: Di Zhang, Jiangchao Qin

**2:00PM***Design and Implementation of Finite State Machine Decoders for Phase Disposition Pulse Width Modulation of Modular Multilevel Converters [#1384]*  
Carlos Teixeira, Yichao Sun, Grahame Holmes and Brendan McGrath   
, RMIT University, Australia; Southeast University, China

It is well known that level shifted phase disposition pulse width modulation (PD-PWM) achieves the best possible three-phase line-to-line output voltage spectrum for multilevel converters. However the strategy does require post modulation signal decoding to optimally select between redundant switched states and to achieve an even distribution of commutation events across all switching devices. For modular multilevel converters (MMCs), PD-PWM involves firstly scheduling the individual module switching events of both arms as an integrated process to achieve optimal harmonic performance, and then selecting between redundant states to balance the individual module capacitor voltages, and to also minimise the phase leg high frequency circulating currents. This paper discusses the design and implementation of finite state machine PD PWM post modulator decoders for MMCs to achieve these objectives. The proposed approach has been verified in simulation and then with experimental confirmation using a two module per arm MMC

**2:25PM***Control of the AC-AC Modular Multilevel Converter under Submodule Failure [#1531]*  
Yang Qichen and Saeedifard Maryam   
, Georgia Institute of Technology, United States

The family of Modular Multilevel Converter (MMC) has become one of the most promising converter topologies for medium/high-voltage applications because of its modularity and scalability. Specifically, the AC-AC MMC is a promising candidate for medium-voltage motor drive applications. As the AC-AC MMC is based on stacking a large number of Submodules (SMs), its operation is vulnerable to SM failure. To improve the reliability/availability of the AC-AC MMC, in this paper, a post-fault strategy is proposed to ensure stable operation and normal power transfer capability of the MMC subsequent to any SM failure. Besides, since proper operation of the AC-AC MMC necessitates that the magnitude of the SM capacitor voltage fluctuations need to be attenuated, SM capacitor voltage fluctuation mitigation strategies are also proposed. Performance and effectiveness of the proposed methods are verified based on simulation studies in the PSCAD/EMTDC software environment.

**2:50PM***Control of a Modular Multilevel Converter with Pulsed DC Load [#400]*  
Marija Jankovic, Alan Watson, Alessandro Costabeber and Jon Clare   
, University of Nottingham, United Kingdom

This paper focuses on a Modular Multilevel Converter grid interface for a klystron modulator system that behaves as a pulsed DC load. With such a load, and without mitigating control, the MMC suffers from cell capacitor voltage imbalance between the converter arms which leads to distortion (fluctuation) of the absorbed AC power. This paper proposes an augmented modulation strategy, with a tailored distribution of the modulation signals between the arms within a phase, to ensure low AC power fluctuation. The effectiveness of the method has been verified through simulation and has been experimentally proven on a 7kW MMC prototype operating with a 3 kA pulsed DC load.

**3:15PM***Short circuit output protection of MMC in Voltage Source Control Mode [#511]*  
Manfred Winkelnkemper, Lukas Schwager, Pawel Blaszczyk, Mischa Steurer and Dionne Soto   
, ABB Switzerland Ltd., Switzerland; ABB Poland Sp. z o.o., Poland; CAPS Florida State University, United States

The MMC operated in Current Source Mode (CSM) with branch current control shows excellent fault limiting capability. With proper design, the same capability is achieved in Voltage Source Mode (VSM). The key is combining the VSM and CSM controls and having same state variables. Seamless transition between CSM and VSM is ensured by the change of references triggered either by the user or by internal limiters. Experimental results in the full scale 1.25 MW demonstrator proved that the MMCs can limit short circuit currents without turning off even when it's shorted at its terminals.

DC-DC: Isolated Convertes

Thursday, September 22, 2:00PM-3:40PM, Room: 102C, Chair: Sudip Mazumder, Jason Stauth

**2:00PM***An Isolated Three-Port DC-DC Converter with High Power Density in 10 cm X 5 cm X 0.8 cm Card Size for Flexible Automotive Systems [#594]*  
Shuntaro Inoue, Kenichi Itoh, Masanori Ishigaki, Takahide Sugiyama and Masaru Sugai   
, TOYOTA CENTRAL R and D LABS., INC., Japan

A credit-card sized three-port dc-dc converter (TPC) has been designed and constructed. The TPC has three DC ports in one circuit, and DC power can be transferred without interference mutually. A dual active bridge converter (DAB) and a non-isolated bi-directional dc-dc converter (NBC) are integrated in the TPC by using a technique known as magnetic coupling inductor. Both thermal and soft-switching analysis are conducted to realize a high energy density of prototype, where a 750 W, 375 kHz, 18 W/cc is achieved. The efficiency and total losses have been measured in order to verify the validity of the proposed converter, and efficiency over 90% in wide range of output power is achieved by using Si MOSFETs.

**2:25PM***Auxiliary power supply based on a modular ISOP Flyback configuration with very high input voltage [#555]*  
Alberto Rodriguez, Maria R. Rogina, Mariam Saeed, Diego G. Lamar, Manuel Arias, Mario Lopez and Fernando Briz   
, University of Oviedo, Spain

This paper proposes a Flyback-based Input-Series Output-Parallel (ISOP) Auxiliary Power Supply (APS), intended to feed the control system of the cells of a Solid-State Transformer (SST). The SST topology is based on a modular Multiport Multilevel Converter (MMC). Energization of the cells auxiliary circuitry is not trivial due to the high voltages involved (tens of kV for the electric power distribution system), most of the commercially available control and driving circuitry not being usable due to the isolation requirements. It is possible to energize the control circuitry from an APS, connected to the cell capacitor voltage. However, in the SST under consideration, cells target DC voltage is in the range of 1.5kV to 2.5kV. Design of an APS capable of feeding the auxiliary circuitry from such high voltage and the required isolation is not trivial. A modular APS using autonomous Flyback converters in Continuous Conduction Mode (CCM) and based on commercial AC adapters is proposed in this paper. The solution is scalable and therefore applicable to cells with larger DC voltages.

**2:50PM***Design Considerations for Series Resonant Converters with Constant Current Input [#707]*  
Hongjie Wang, Tarak Saha and Regan Zane   
, Utah State University, United States

Applications such as under-sea power prefer dc current distribution in a series cable connection instead of dc voltage distribution due to the long distance and cable loss. Power converter modules employed in these scenarios have a constant current input. In this paper, steady state analysis and unique design considerations are presented for the series resonant converter topology with constant current input. Constraints on the resonant tank component selection and operating frequency are developed to achieve the desired load range for the given input current. Hardware results are provided based on an under-sea dc distribution scenario to verify the benefits of the analysis and design considerations for a 400 kHz, 500 W SRC with 1 A input current and 330 mA output current.

**3:15PM***Galvanically Isolated Switched-Boost-Based DC-DC Converter [#123]*  
Saman A. Gorji, Mehran Ektesabi, Trung N. Nguyen and Jinchuan Zheng   
, Swinburne University of Technology, Australia

A new galvanically isolated DC-DC converter has been presented in this paper. The proposed topology is based on the quasi-switched-boost impedance network. It not only includes all positive characteristics of previous converters including continuous input current, high boost ability and high efficiency, but also has the prominent features of less passive elements utilization, small size and light weight. The proposed converter has been analyzed and inspected in the steady state. Furthermore, other possible galvanically isolated switched boost dc-dc topologies have been obtained by altering the switching network. Theoretical analysis has been verified by simulations as well as the experiments.

Modeling and Control of DC-AC converters II

Thursday, September 22, 2:00PM-3:40PM, Room: 202D, Chair: Thomas Jahns, Jon Are Suul

**2:00PM***A Triangle Phase-Shift Control Strategy for Interleaved Critical-Mode Power Converters [#541]*  
Lanhua Zhang, Rachael Born, Qingqing Ma, Yu Wei, Xiaonan Zhao and Jih-Sheng Lai   
, Virginia Polytechnic Institute and State Univers, United States

Due to its high conversion efficiency and high power density, interleaved critical-mode converter is widely employed by modern power converters. This topology is utilized in ac-dc, dc-dc, and dc-ac converters. Because of the variable switching-frequency operation, phase-shift control is a challenge in the design of critical-mode power converters. This paper presents a triangle phase-shift control strategy for interleaved critical-mode power converters. Based on circuit parameters of the topology and current information of the master phase, a control ramp is derived to control the current phase of slave phase. Based on the proposed control ramp, triangle phase-shift control is proposed. The proposed control strategy is experimentally verified on a dual- phase interleaved dc-dc converter.

**2:25PM***Seamless Transition Control between Motoring and Generating Modes of a Bidirectional Multi-Port Power Converter Used in Automotive SRM Drive [#1173]*  
Fan Yi, Wen Cai and Babak Fahimi   
, The University of Texas at Dallas, United States

In this paper, a control strategy providing seamless transition between motoring and generating modes within a bidirectional integrated multi-port power converter (IMPC) used in switched reluctance machine (SRM) drive is presented. The IMPC offers capacitance reduction in the dc bus while maintaining a very small ripple on the input current from or output current to the dc source under both modes of operation. This facilitates a direct connection to the battery pack in an electric propulsion system. In addition, the braking torque can be controlled even under high speed thanks to the adjustable dc bus voltage. Model of the SRM drive system incorporating the converter and SRM is established for both motoring and generating modes. Accordingly, the seamless transition strategy is developed based on IMPC. Finally, the effectiveness of the proposed system is validated by simulation and experimental results.

**2:50PM***Three-Phase Inverter Modeling using Multifrequency Averaging with Third Harmonic Injection [#500]*  
Xiao Liu and Aaron Cramer   
, University of Kentucky, United States

Models of converters based on averaging have been used widely with numerous benefits. Multifrequency averaging (MFA) model can predict both the fundamental and switching behavior of converters and has the faster simulation run times associated with average-value models. Third harmonic injection is commonly used in the modulation signal for three-phase inverters to increase the inverter maximum output voltage while avoiding overmodulation. Herein, an MFA model for three-phase pulse width modulation inverters with third harmonic injection is proposed. The quasi-Fourier-series representation of the switching functions with third harmonic injection is necessary for constructing three-phase inverter MFA model. The third harmonic injection does not change the fundamental and third harmonic components of the state variables in a balanced three-phase system, but it changes the higher-order harmonics. As a result, the quasi-Fourier-series representation of the switching functions for three-phase inverters with third harmonic injection must include the third harmonics. The proposed MFA model is demonstrated in simulation, and the simulation results show that this model has high accuracy (including the switching behavior) and fast run times.

**3:15PM***Transformation Based Tracking Controller for a GaN Microinverter [#978]*  
Ankit Gupta, Harshit Soni, Sudip Mazumder, Shirish Raizada, Debanjan Chatterjee, Paromita Mazumder and Parijat Bhattacharjee   
, University of Illinois, United States; Tagore Tech, United States; NextWatt LLC, United States

Differential mode cuk inverter (DMCI) represents a class of single-stage inverter with low device count, modular symmetry, and topological simplicity. Recently, discontinuous modulation scheme (DMS) has been proposed for the DMCI. This paper extends the modular nature of the power stage to the control architecture and proposes a transformation based tracking controller using adaptive control algorithm for the same. A key challenge in designing a controller for DMS based DMCI is to take into account the inherent converter nonlinearity and startup transient at the start of every line cycle. Experimental results are provided for startup, steady state, load transition, and total harmonic distortion (THD) using GaN FET based DMCI, which validate the efficacy of the implemented modular transformation-based tracking controller.

Stability in Power Converters II

Thursday, September 22, 2:00PM-3:40PM, Room: 102E, Chair: Dusan Borojevic, Leila Parsa

**2:00PM***Source-side Series-virtual-impedance Control Strategy to Stabilize the Cascaded System with Improved Performance [#547]*  
Xin Zhang, Qing-Chang Zhong and Wen-Long Ming   
, The University of Sheffield, United Kingdom; Illinois Institute of Technology, United States

For cascaded system, interactions among individually designed power subsystems may cause the instability of the whole system. It has been shown recently that the series-virtual-impedance (SVI) control strategy can stabilize the cascaded system via shaping the load input impedance in a very small frequency to minimize its impact on the original load converter. In this paper, a further investigation of the SVI control strategy is carried out by two-port network analysis. Firstly, it is pointed out that, though the impact of the SVI control strategy is limited in a very small frequency, it still deteriorates the performance of the original load converter. In order to overcome this drawback, this paper proposes source-side series-virtual-impedance (SSVI) control strategy, which move the series-virtual- impedance of the traditional SVI control strategy from load side to source side by changing the control of the source converter instead of the load converter. With the proposed SSVI control strategy, the cascaded system not only can solve its instability problem, but also can improve the performance of its source converter. Finally, a 100W 48V-32V-24V experimental system is fabricated to validate the SSVI control strategy.

**2:25PM***Bifurcation Analysis of Photovoltaic-Battery Hybrid Power System with Constant Power Load [#939]*  
Meng Huang, Lijun Wei, Yi Liu, Jianjun Sun and Xiaoming Zha   
, Wuhan University, China

The photovoltaic-battery hybrid power system is a kind of flexible renewable power generation system, which is composed of a photovoltaic array and a battery connected to an output DC bus via power converters. The system can work with multiple structures and multiple operating modes due to the source and load states. Particularly, the nonlinear nature of the constant power load will destablize the system under different operating modes. In this paper, the bifurcation phenomena are identifed in this kind of system when the local load working as a constant power load. It is obersed that the loading has a nonlinear impact on the system and leads to low-frequency Hopf bifurcation and catastrophic bifuration which is an irreversible instability in the system. Based on the averaged model, the two bifurcation is analyzed and the stability boundaries are located. Finally, the instability phenomena are verified by experimental measurements in a practical PBHPS of 200 W.

**2:50PM***Measurement technique to determine the impedance of automotive energy nets for stability analysis purpose based on a floating capacitor H-bridge converter [#505]*  
Matthias Hiermeier, Michael Muerken, Thomas Hackner and Johannes Pforr   
, Technische Hochschule Ingolstadt, Germany; Audi AG Ingolstadt, Germany

The complexity of electrical energy nets in modern cars is increasing rapidly due to the rising number of dc-dc converters and motor controllers. Multi-converter systems may lead to negative impedance instability that must be avoided in the automotive energy net under all circumstances, including faulty conditions such as a failure of batteries or other energy storage devices. Many stability criteria that have been developed during the last years for multi-converter systems are impedance based stability criteria. Impedance measurements therefore play an important role when investigating stability issues of multi-converter systems. In this paper a floating capacitor H-bridge converter is proposed as a simple measurement device for impedance measurements in automotive energy nets. The device can be easily implemented, provides small size and weight and is able to cope with the high dc currents required by the loads. A full-size prototype converter was built and tested to prove the performance for the given application. Theoretical predictions are in good correlation with experimental results.

**3:15PM***Harmonic Suppression and Stability Improvement for Aggregated Current-Controlled Inverters [#39]*  
Qiang Qian, Shaojun Xie, Jinming Xu and Lin Ji   
, Nanjing University of Aero. and Astronautics, China

For LCL-filtered grid-connected inverters, classical control methods such as the proportional grid voltage feed-forward, the harmonic quasi resonant (HQR) control etc., are widely utilized to achieve low current distortion. However, the system stability is easily challenged by the grid impedance and the increased number of the paralleled inverters. Therefore, this paper orients to guarantee the harmonic suppression and the system stability, simultaneously. The impedance-based approach is employed for modeling the multiple-inverter system. The control strategy which consists of the proportional weighted grid voltage feed-forward and HQR with phase compensation is proposed. Moreover, the relationship between the proportional weighted value and the number of the improved HQR controllers is clearly clarified. With the help of the proposed control strategy, the magnitude of the inverter output impedance is maximized as much as possible and the phase across -90 degree is avoided to improve the system stability. The effectiveness of the method is verified with experimental results on a two-inverter-parallel system

Design Optimization of Power Converters

Thursday, September 22, 2:00PM-3:40PM, Room: 202C, Chair: Suman Debnath, Pericle Zanchetta

**2:00PM***Efficiency-wise Optimal Design Methodology of LCLC Converter for Wide Input Voltage Range Applications [#101]*  
Yang Chen, Hongliang Wang, Zhiyuan Hu, Yan-fei Liu, Jahangir Afsharian and Zhihua (Alex) Yang   
, Queen's University, Canada; Murata Power Solutions, Canada

LCLC converter is an LLC-based, four-element resonant topology, which has been proved to achieve high voltage gain and high efficiency. Such trait makes LCLC converter specifically suitable for wide-input-voltage-range DC/DC applications. Currently, LCLC converter lacks a design method targeting at optimal efficiency over a wide input voltage range. In fact, due to the complexity, efficiency itself is seldom used as optimization criterion even for LLC designs. In this paper, a systematic methodology is proposed to optimize the efficiency at different input voltage levels for LCLC converter. Three mathematical programs (developed in MATLAB) are employed respectively to find all resonant parameter combinations that critically achieve the required voltage gain; precisely analyze the current stress in time domain; and comprehensively calculate the losses in the power circuit including magnetic components. The programs will automatically generate the optimal parameter design with highest weighted efficiency at desired input voltage levels, as well as the magnetic components construction with specified types and sizes of core and conductor. Besides, this method can be extended to other topologies for wide voltage range applications. To verify the effectiveness of the proposed optimal design method, the function of the mathematical tools will be carefully explained in this paper; and a step-by-step design will be demonstrated as an example. Simulation will be included to verify the accuracy of the method.

**2:25PM***Reliability-Oriented Design of LC Filter in Buck DC-DC Converter with Multi-Objective Optimization [#598]*  
Yi Liu, Meng Huang, Yuexia Liu and Xiaoming Zha   
, School of Electrical Engineering, Wuhan Universi, China

Reliability-oriented design has been proved to be a kind of effective design methodology for power electronic equipment. This paper proposes a design method to obtain the value of inductance and capacitance sets that obtain high capability, power density, high reliability of an LC filter in buck converters through a multi-objective optimization way. The cut-off frequency, lifetime of capacitor and total volume of LC filter are set as objectives in the optimization procedure. The relationship of design objectives and parameters are analyzed. The distribution of these objects and corresponding parameters as well as the Pareto front of the objectives are presented. Simulation and experiment results are presented and verified the theoretical analysis.

**2:50PM***Optimal Design of Output LC Filter and Cooling for Three-Phase Voltage-Source Inverters Using Teaching-Learning-Based Optimization [#880]*  
Hamzeh Jamal, Saher Albatran and Issam Smadi   
, Jordan University of Science and Technology, Jordan

Three-phase voltage-source inverters are becoming widely used in grid applications, due to the increased utilization of renewable energy resources such as photovoltaic (PV) systems. The connection of the inverter to the grid must not deteriorate the voltage quality at the point of the common coupling (PCC). Therefore, the injected current harmonics must not exceed certain level. Reduction of the injected harmonics can be achieved by increasing the filter size and/or increasing the switching frequency. However, increasing the switching frequency will increase the losses in the inverter due to the switching actions. On the other hand, increasing the filter size will increase the cost of the filter. In this paper, an optimal simultaneous design method which aims to minimize the output LC filter cost and the cooling cost with the switching frequency being the main design parameter is proposed. The cooling and filtering components are expressed in terms of the switching frequency. An optimization problem was formulated to find the minimum cost design, constrained by thermal and harmonic limits in addition to another constraints related to the design of the filter. The optimization problem is solved by means of Teaching-Learning-Based Optimization (TLBO) algorithm. The importance of the proposed design method is that the selection of the switching frequency is based on mathematical formulation rather than relying solely on the experience of the designer.

**3:15PM***Using design by optimization for reducing the weight of a SiC switching cell [#678]*  
Mylene Delhommais, Gnimdu Dadanema, Yvan Avenas, Jean-Luc Schanen, Francois Costa and Christian Vollaire   
, G2ELab, France; Satie, France; Ampere, France

This paper uses the design by optimization method to determine the best combination of passives, EMC filter, heatsink, taking into account the components constraints, in order to reduce the weight of a SiC switching cell, implemented in a simple buck converter. All elements and associated restrictions are described using analytical expressions, and the optimizer performs the reduction of the objective function (weight) respecting all constraints. The models and the optimization strategy are described, and the optimization results are presented and discussed, in comparison with a conventional Si switching cell.

Active Power Filters

Thursday, September 22, 2:00PM-3:40PM, Room: 101B, Chair: Luis Moran, Andy Knight

**2:00PM***Multilevel Nine-Leg Converter Universal Active Power Filter [#1174]*  
Phelipe Leal Serafim Rodrigues, Cursino Brandao Jacobina and Mauricio Beltrao de Rossiter Correa   
, DEE UFCG, Brazil

This paper presents a multilevel universal active power filter (UAPF) topology with nine legs. The proposed system is a combination of two series and one shunt active power filters with a connection series-shunt-series. It is suitable to improve the harmonic distortion in the grid currents and a voltage compensation. The filter is composed of three three-phase converters resulting in nine legs sharing a single DC-link. The complete control system, including the PWM techniques of the proposed topology for different transformers turn ratios, is developed. Simulation and experimental results are shown for validation purposes.

**2:25PM***Central Control and Distributed Protection of the DSBC and DSCC Modular Multilevel Converters [#1539]*  
Andre Hillers, Hao Tu and Juergen Biela   
, Laboratory for High Power Electronic Systems, Switzerland; North Carolina State University, United States

The benefits of modular multilevel converters come at a price: Their high level of complexity demands for an intricate design methodology and a sophisticated control structure. This is especially true for converters that need to be able to recover from short-circuits, grid faults, communication faults or module faults. In order to build a reliable system, it is thus important to understand the effect that the control structure has on the converter design. When protecting each module against overvoltages and overcurrents individually, the performance of the central controller is no longer immediately safety critical. This allows to communicate the switching times and measurements with a daisy-chain-like communication architecture that does not require point-to-point connections from the central controller to every module. The presented approach is verified by time-domain simulations and validated on a downscaled hardware prototype system.

**2:50PM***Mitigating the Effect of Series Capacitance Unbalance on the Voltage Reduction Capability of an Auxiliary CSI used as Switching Ripple Active Filter [#1545]*  
Savvas Papadopoulos, Mohamed Rashed, Christian Klumpner and Pat Wheeler   
, University of Nottingham, United Kingdom

The use of series connected capacitors for high voltage applications has been proven to be beneficial for voltage stress reduction across power semiconductors. In a 3-phase grid any asymmetry in the value of the series capacitance may lead to significant variations in the voltage seen across the low voltage converter. This paper investigates the effects of an unbalanced set of series connected capacitors used to reduce the voltage stress across a three phase current source inverter (CSI) used as an active power filter and proposes a method to minimize the impact of unbalance on CSI voltage ratings. It is shown that through a proposed solution which adjusts the level of inverse sequence current component in the series capacitors, the reduced CSI voltage stress can be maintained for large capacitor unbalance and validated by simulation and experimental results.

**3:15PM***A New Control Method of Suppressing DC-Capacitor Voltage Ripples Caused by Third-Order Harmonic Compensation in Three-Phase Active Power Filters [#1375]*  
Tomoyuki Mannen, Issei Fukasawa and Hideaki Fujita   
, Tokyo Institute of Technology, Japan

This paper proposes a new control method suitable for active power filters to reduce the dc capacitor voltage ripples associated with the third-order harmonic current compensation. The proposed method superimposes a negative-sequence fundamental current on the compensating current to cancel out the active power ripple caused by the third-order harmonic current. As a result, the proposed method has the capability to eliminate the dc capacitor voltage ripple at double the source frequency. Experimental results obtained by a 10-kW three-phase diode rectifier verify the validity of the proposed method. The proposed method exhibits a good suppression performance of the dc capacitor voltage ripple at double the source frequency.

Non-Conventional Machine Configurations II

Thursday, September 22, 2:00PM-3:40PM, Room: 101A, Chair: Guan-Ren Chen, Nicola Bianchi

**2:00PM***Design of Dual Purpose No Voltage Combined Windings for Bearingless Motors [#1524]*  
Eric Severson, Robert Nilssen, Tore Undeland and Ned Mohan   
, University of Minnesota, United States; NTNU, Norway

A winding design approach is proposed to create a single motor winding which is able to produce both radial force and torque. This approach can be used to design new bearingless motors as well as to transform conventional motor designs into bearingless motors by simply modifying the winding end- connections. The resulting winding has two sets of terminal connections: one for torque and one for suspension. The suspension terminals experience no motional-EMF when the rotor is centered, which means that the suspension drive can have a low voltage rating and that rotor vibrations can be passively dampened by simply short-circuiting the suspension terminals. Bearingless motors that use these so-called ``dual purpose no voltage windings" can be designed to have higher torque density and lower losses associated with the magnetic suspension operation than traditional bearingless motors which utilize separate torque and suspension windings. It will be shown that many popular winding designs, including fractional- slot and concentrated windings, can be realized as dual purpose no voltage windings. The proposed approach applies to traditional p +- 1 pole-pair bearingless motors as well as the bearingless consequent-pole and ac homopolar motors. Fractional-slot motor winding theory is used to derive the new winding requirements and a generalized design procedure; example designs are explored through finite element analysis and experimental results from a hardware prototype of a bearingless ac homopolar motor.

**2:25PM***Synchronous Generator Field Excitation Via Capacitive Coupling Through a Journal Bearing [#629]*  
Jiejian Dai Dai, Skyler Hagen, Daniel Ludois and Ian Brown   
, University of Wisconsin -Madison, United States; Illinois Institute of Technology, United States

Wound field synchronous generators (WFSG) are the standard for back-up and utility scale power generation. Rotor field current and prime mover speed are the only control parameters required to regulate power conversion in a generator application. Maintenance costs may be minimized by adopting non- contact or brushless technologies to replace sliding slip ring connections. This paper presents a brushless excitation approach using ceramic insulated sleeve or journal bearings with oil lubrication to form capacitively coupled slip rings, in contrast to more traditional inductive brushless exciters and rotary transformers. This capacitive power transfer CPT approach exhibits advantages including low weight, low volume and has a relatively simple construction using off-the-self components. Analysis, design and prototype construction of the CPT system are presented. Experimental results demonstrate that 1.7nF of capacitive couplingtransfers 340W to the rotor field winding of a 10kW 208V WFSG. Voltage regulation of a WFSG is demonstrated during steady state and 1 per unit load step changes yielding a NEMA-MG1 class G2 rating.

**2:50PM***Development of Stator-Magnetless Linear Synchronous Motor for Sensorless Control [#314]*  
Makino Shogo, Kakihara Masanobu, Takase Yoshiyasu, Takaki Mamoru, Shikayama Toru, Ohto Motomichi, Higuchi Tsuyoshi and Abe Takashi   
, Yaskawa Electric Corporation, Japan; Nagasaki University, Japan

Sensorless control technique is desired in applications of a long stroke linear synchronous motor (LSM) without using a linear scale. This paper discusses the development of a stator-magnetless LSM (no magnet mounted on the stator of LSM) for sensorless control technique that includes a high speed position estimation algorithm based on magnetic hysteresis phenomenon. This paper presents the new structure of a flux-switching LSM to achieve a high saliency ratio by designing a cutout which causes magnetic saturation in the armature core. The effect of sub-teeth to reduce cogging thrust is also presented. Furthermore, this paper also reports the analytical and experimental characteristics of inductance, thrust, cogging thrust, and sensorless control drive using a prototype.

**3:15PM***Ultralightweight Motor Design Using Electromagnetic Resonance Coupling [#201]*  
Kazuto Sakai and Yuta Sugasawa   
, Toyo University, Japan

To produce an ultra-lightweight motor, we propose a technology that converts electrical energy between the stator and rotor using magnetic coupling. Magnetic coupling causes electromagnetic resonance between the respective multiphase windings of the stator and rotor. Electromagnetic resonance coupling technology allows electric motors to convert energy without magnetic cores, significantly reducing their overall weight. In this study, we proposed a motor design based on magnetic resonance coupling (MRC) and described its operating principles and characteristics. A model of the proposed MRC motor was analyzed using magnetic analysis to verify its rotational energy conversion and understand its fundamental characteristics. Our results confirmed that the proposed MRC motor without a magnetic core is capable of converting electromagnetic energy between the stator and rotor and producing sufficient operating torque.

Magnetic Gears

Thursday, September 22, 2:00PM-3:40PM, Room: 102B, Chair: Siavash Pakdelian, Kan Akatsu

**2:00PM***A Novel Reluctance Magnetic Gear for High Speed Motor [#1667]*  
Kohei Aiso and Kan Akatsu   
, Shibaura institute of technology, Japan; Shibaura Institute of Technology, Japan

In the industrial field, the drive system integrated the high speed motor and the gear is required to effectively utilize the limited space. However, mechanical gears often require their lubrication and cooling, they generate whilst noise and vibration. To overcome these problems, the magnetic gears have been expected. Magnetic gears achieve the system with maintenance-free, low noise and low vibration characteristics by contact-less power transformation. However, conventional magnetic gears are not suitable system for high speed motors because the mechanical strength is weak due to permanent magnets of the high speed rotor. Adding that, the magnet eddy current loss in the high speed rotor seriously decreases the gear efficiency in high speed drive. This paper presents a novel reluctance magnetic gear for the super high speed motor. The high speed rotor of the proposed magnetic gear is constructed by only iron core. Therefore, the structure is very simple and robust and it is possible to rotate in the high speed region. Moreover, the magnetic gear achieves high efficiency in the high speed region because the magnet eddy current loss in the high speed rotor is not generated because of having no magnets. The downsizing of the system and high efficiency power transfer are realized by applying the reluctance magnetic gear.

**2:25PM***Analysis of a Magnetically Geared Lead Screw [#1277]*  
Mojtaba Bahrami Kouhshahi and Jonathan Bird   
, Portland State University, United States

Linear magnetic gearboxes (LMG) and magnetic lead screws (MLS) have been shown to be capable of operating at significantly higher volumetric force densities than traditional electromagnetic linear actuators (ELA). However in both such devices the linear translator must be made of magnet material and therefore if the stroke length of the translator is long the cost of the MLS and LMG will become prohibitively high. In this paper a magnetically geared lead screw (MGLS) is investigated and its performance capability is compared with the LMG and MLS. The advantage of the MGLS is that the translator does not contain magnets.

**2:50PM***Design Comparison of NdFeB and Ferrite Radial Flux Magnetic Gears [#1358]*  
Matthew Johnson, Matthew C. Gardner and Hamid A. Toliyat   
, Texas A and M University, United States

Magnetic gears promise the benefits of mechanical gears with added advantages from contactless power transfer. Although most literature focuses on minimizing the size of magnetic gears, their material costs must also be reduced to achieve economic feasibility. This work compares the active material costs of NdFeB and ferrite radial flux magnetic gears with surface permanent magnets through a parametric 2D and 3D finite element analysis (FEA) study. Differences in optimal design trends such as pole count and magnet thicknesses are illustrated for the two materials. The results demonstrate that, for most historical price combination scenarios, NdFeB gear designs are capable of achieving lower active material costs than ferrite gear designs, and they are always capable of achieving much higher torque densities. Based on the selected design constraints, relative to a nominal ferrite cost of $10/kg, NdFeB must cost more than $90/kg before ferrite is cost competitive. Additionally, contour plots are provided to show the impact of material price rate variation on the cost break points.

**3:15PM***Power Transferring of Magnetic-Geared Permanent Magnet Machines [#364]*  
Leilei Wu, Ronghai Qu, Dawei Li and Yuting Gao   
, Huazhong University of Science and Technology, China

Due to the high torque density and sharing similar operating principles with vernier machines, the magnetic-geared permanent magnet machines have been gaining more attention recently. This paper focuses on power transferring feature of a magnetic geared machine among the stator, modulation layer and rotor by analytical methods. Analytical equations of the back electromotive force (back EMF), torque and power are derived. It is found that the power expression is a function of gear ratio between modulation layer and rotor. In addition, the influence of the parameters on the back EMF and torque are also discussed. Finally, the analytical results are verified by the finite-element analysis (FEA), and the good agreements have been achieved.

High Speed and Direct Drives

Thursday, September 22, 2:00PM-3:40PM, Room: 101CD, Chair: Mazharul Chowdhury, Rukmi Dutta

**2:00PM***Robust Control of an Open-Ended Induction Motor Drive With a Floating Capacitor Bridge over a Wide Speed Range [#1629]*  
Michele Mengoni, Albino Amerise, Luca Zarri, Angelo Tani, Giovanni Serra and Domenico Casadei   
, University of Bologna, Italy

An electric drive for high-speed applications is analyzed in this paper. The drive consists of a dual two-level inverter with a floating bridge, fed by a single voltage source, and a 3-phase induction motor with open-ended stator windings. The floating bridge compensates the reactive power of the motor, so that the main inverter operates at unity power factor and fully exploits its current capability. The constant power speed range of the motor can be significantly extended depending on the DC-link voltage of the floating inverter. The details of the control system are examined and the feasibility of an electric drive is experimentally assessed.

**2:25PM***High speed operation of permanent magnet machine position sensorless drive using discretized EMF estimator [#596]*  
Shih-Chin Yang and Guan-Ren Chen   
, National Taiwan University, Taiwan

This paper proposes a permanent magnet (PM) machine position sensorless drive for high speed (>10-krpm) applications. A fully discretized back electromotive force (EMF) estimator is designed to overcome several high speed rotor position estimation issues, including the voltage error due to pulse-width- modulation (PWM), dq inductance cross-coupling effect and the deviation between the estimated EMF and actual EMF resulting from the digital implementation. To overcome these problems, an observer-based EMF estimator is proposed with two implementation considerations. They are i) a discretized dq current observer to minimize the inductance cross-coupling effect on the estimated EMF voltages, and ii) a PWM model considering the EMF cross-coupling effect to obtain actual EMF voltages. A high speed PM machine is experimentally tested to verify all proposed sensorless drive methods.

**2:50PM***DC Voltage Regulated PWM Inverter for High-Speed Electrical Drives [#1507]*  
Vito Giuseppe Monopoli, Maria Concetta Poliseno, Maria Chiara Stomati and Francesco Cupertino   
, Politecnico di Bari, Italy; GE Avio srl, Italy

This paper presents a study on two converter topologies suitable for driving high-speed three-phase electrical machines. In such applications the use of standard inverters with Si-based IGBTs may lead to high switching losses due to the elevated fundamental frequencies of high-speed machines. The use of wide band-gap devices allows reducing losses at high switching frequencies but problems related to EMI and accelerated motor insulation aging may occur. In this work a DC-DC converter is introduced to limit the inverter switching frequency at motor terminals without reducing the sampling frequency of the motor control scheme. This scheme allows to reduce EMI phenomena, and insulation stress on the motor with positive impact also on converter total losses at very high fundamental frequencies. Experimental results are also presented.

**3:15PM***Variable Time Step Control with Synchronous PWM in Low Frequency Modulation Index for AC Machine Drive [#881]*  
Sungho Jung, Jaeyong Park, Euihoon Chung and Jung-Ik Ha   
, Seoul National University, Korea (South)

This paper proposes a variable time step controller with synchronous PWM. Since a frequency modulation index is low in an ultra-high speed or high power drive system, the modulated voltage by a fixed time step control includes large harmonic components. The optimal PWM method is one of the solution to minimize the harmonic components, but it needs many offline calculations and its structure is complicated. The proposed variable time step control has small calculation burden and it does not need offline calculations. Furthermore, the harmonic components of the modulated voltage is small because the frequency modulation index is kept as integer value in all speed conditions. Also, the transition strategy between synchronous PWM methods is proposed and it is verified with simulation and experimental results.

Power Assemblies

Thursday, September 22, 2:00PM-3:40PM, Room: 102A, Chair: Jelena Popovic, Yvan Avenas

**2:00PM***Implementation and Performance of a Current Sensor for Laminated Bus Bar [#721]*  
Yoshikazu Kuwabara, Keiji Wada, Jean-Michel Guichon, Jean-Luc Schanen and James Roudet   
, Tokyo Metropolitan University, Japan; G2Elab, Univ. Grenoble Alps, France

This paper presents a current sensor embedded in a laminated bus bar. The proposed sensor is based on the Rogowski coil principle and it can detect the magnetic flux corresponding to a derivative waveform of the current within the bus bars. The frequency characteristics of the current sensor including the parasitic parameters depending on the circuit geometry are discussed. After the design of the current sensor using a PEEC-based software, the proposed sensor was implemented using four- layers and three PCBs. It is confirmed that the verification of the proposed current sensor embedded in the laminated bus bar can be performed by the measurement of turn- on and -off switching waveforms using a buck converter circuit, rated at 50 V and 4 A.

**2:25PM***Busbar Design for SiC-Based H-Bridge PEBB using 1.7 kV, 400 A SiC MOSFETs Operating at 100 kHz [#1640]*  
Niloofar Rashidi Mehrabadi, Igor Cvetkovic, Jun Wang, Rolando Burgos and Dushan Boroyevich   
, CPES- Virginia Tech, United States

This paper presents a systematic study of the busbar design and optimization for SiC-based H-bridge power electronics building block (PEBB) used in high-frequency and high-power applications. Step-by-step guidelines are presented in which the design considerations and analysis are given. This paper presents a double-sided busbar concept to create a compact PEBB design with improved thermal and switching performance, which result from having double-side cooling and symmetric minimized current commutation loop inductances, respectively. The proposed concept is verified experimentally by evaluating the high-speed switching performance of the PEBB up to 400 A.

**2:50PM***Ultra-low Inductance Design for a GaN HEMT Based 3L-ANPC Inverter [#548]*  
Emre Gurpinar, Francesco Iannuzzo, Yongheng Yang, Alberto Castellazzi and Frede Blaabjerg   
, University of Nottingham, United Kingdom; Aalborg University, Denmark

In this paper, an ultra-low inductance power cell design for a 3L-ANPC based on 650 V GaN HEMT devices is presented. The 3L-ANPC topology with GaN HEMT devices and the selected modulation scheme suitable for wide-bandgap (WBG) devices are presented. The commutation loops, which are the main contributors to voltage overshoots and increase of switching losses, are discussed. The ultra-low inductance power cell design based on a four layer PCB with the aim to maximise the switching performance of GaN HEMTs is explained. Gate driver design for GaN HEMT devices is presented. Common-mode behaviours based on SPICE model of the converter is analysed. Experimental results on the designed 3L-ANPC with the output power of up to 1 kW are presented, which verifies the performance of the proposed design in terms of ultra-low inductance.

**3:15PM***Layout Study of Contactless Magnetoresistor Current Sensor for High Frequency Converters [#1374]*  
Mehrdad Biglarbegian, Shahriar Jalal Nibir, Hamidreza Jafarian, Johan Enslin and Babak Parkhideh   
, University of North Carolina at Charlotte, United States; Energy Production and Infrastructure Center, United States

In this paper, we present a new technique to unify and intensify the magnetic fields that results in higher performance of Anisotropic Magneto- Resistive (AMR) current sensors and consequently develop a closed loop controller for 100W synchronous GaN buck converter at 1 MHz. The closed loop operation of high switching frequency converters at high power has always been a big challenge due to lack of access to current information. The proposed method that also intensifies the magnetic fields through the sensor, significantly improves the bandwidth limits, and reduces electromagnetic interference (EMI) on AMR sensors, making them applicable for high switching frequency and high current power electronics converters. After verifying uniform distribution concept through simulation, we also implemented a prototype of AMR current sensors onto Printed Circuit Board (PCB) for verification of the concept at high frequency converter. We then present the design procedure and associated challenges of an integrated analogue peak current controller for creating the closed loop operation of a GaN buck converter at high switching frequency.

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