# Table of Contents

- ECCE 2021 Sponsors ................................................................. 3
- Welcome from General Chair ............................................. 5
- Welcome from Technical Program Committee ..................... 6
- 2021 Organizing Committee .................................................. 7
  - Program Subcommittees ...................................................... 9
- Schedule-at-a-Glance ............................................................. 12
- Plenary Session ..................................................................... 17
- Special Sessions .................................................................... 20
- Tutorials ................................................................................ 41
- Technical Program ................................................................. 51
- Technical Session Chairs ...................................................... 135
- Product Sessions ................................................................... 141
- Student Demonstrations ....................................................... 142
- Exhibitor Listing ................................................................... 143
- ECCE 2022 INFORMATION .................................................. 144
  - Call for Papers ................................................................... 144
  - Call for Tutorials ................................................................ 145
  - Call for Special Session Organizers ................................. 147
The ECCE 2021 Organizing Committee would like to express its gratitude for the generous support received from the following:

**GOLD SPONSOR**

STMicroelectronics

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OPAL-RT Technologies

**INDUSTRY SPONSOR**

GMW Associates
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On behalf of the entire ECCE 2021 Organizing Committee it is my pleasure to welcome you to the 13th Energy Conversion Congress and Expo, ECCE 2021, co-sponsored by the IEEE Industry Applications Society (IAS) and IEEE Power Electronics Society (PELS). Joining IAS and PELS this year are STMicroelectronics as a Gold Sponsor and OPAL-RT as a Silver Sponsor. Please visit their booths in the user-friendly virtual exhibit, where you’ll also find many other companies which will provide you with information on their newest products and solutions.

Since its debut in 2009, ECCE has become the key annual event to attend if you, like me, are passionate about electrical and electromechanical energy conversion technology and if you enjoy sharing your ideas with other engineers, students and researchers from industry and academia. In the spirit of worldwide inclusion, ECCE 2021 is virtual, on a user-friendly platform, and with a plethora of events focused on giving you the opportunity to learn, network and discover what’s new and trending in integrated energy systems as well as individual energy conversion components.

ECCE 2021’s program features four live plenary talks by experts and leaders from Tesla, MagniX, General Electric Aviation, and Intel. They will present the latest energy conversion technologies and their visions for future research and development. Adopting the same live format as the plenary session, several special sessions will provide you with opportunities to participate in panels with experts from industry and academia. The topics are very timely and important ranging from additive manufacturing for electric machines to wide bandgap devices, from power electronics to interface distributed energy resources to standard development, from energy access for all countries to cybersecurity, from power converters as grid-interface to simulations, controls and thermal design.

The tutorial program opens the conference on Sunday with several informative and engaging live sessions. Thanks to the virtual format, you can access the tutorial presentations a few days before Sunday, to get the most out of the live sessions with the tutorial presenters. The topics include grid-forming technology, wide bandgap devices, electric machine design, electric drives, solar photovoltaic and energy storage systems, design practices, electromagnetic interference, resilience, reliability and electro-thermal design.

At the core of ECCE 2021, is the regular technical program, with almost 900 technical papers and as many on-demand oral presentations, which deliver the latest advancements in energy conversion technology with focus both on components and systems. I hope you’ll enjoy interacting with the authors, at your own pace, through the chats available for each technical presentation throughout the conference. Two of these sessions are dedicated to Prof. Akira Nabae and Prof. Braham Ferreira, who recently passed away and were attendees of many ECCE conferences. They left their imprint on the field of energy conversion through their research contribution and through their many students; we will never forget them.

Following the tradition of the past few years, ECCE 2021 is co-located with the 2021 IAS Annual Meeting. We share the plenary session, the award presentations and the exhibit hall, which is free for everybody. If you are a student, you have access to both technical programs.

The ECCE 2021 program was created by an extraordinary and diverse team of volunteers, women and men from the industry, government laboratories, and academia who selflessly donated their time and talent to ECCE 2021 for almost two years. The contribution from IEEE personnel, SmithBucklin and Vfairs was also instrumental in organizing this conference. Thank you for making ECCE 2021 as engaging in virtual format as it has been in-person in past years.

I invite you to enjoy the 5 live days, and to also take advantage of the additional 25 days during which the on-demand content, including exhibitor materials, technical presentations, recorded live sessions and panels, product sessions, award presentations and student demonstrations, will be available on the virtual platform.

Thank you for participating in ECCE 2021. Together, we contribute to a more sustainable world!

Giovanna Oriti
ECCE 2021 General Chair
Welcome from Technical Program Committee

On behalf of the Technical Program Committee it is our great pleasure to welcome you to the IEEE Energy Conversion Congress & Exposition (ECCE 2021). We were hoping to resume the in-person meeting this year or to have a hybrid conference at the very least. Unfortunately, this turned out to be impossible, but we hope that the virtual mode meets your expectations. We created an exciting program for all virtual attendees with live events such as tutorials, special sessions, plenary sessions and the expo, and we combined it with prerecorded videos for the rest of the technical program.

The world’s leading conference on energy conversion systems, ECCE, is sponsored by the IEEE Industry Applications Society (IAS) and IEEE Power Electronics Society (PELS). It offers a multidisciplinary array of topics, ranging from devices to electrical power systems. Almost 900 technical presentations are organized into thematic sessions, with offline Q&A that authors will monitor daily. The material of the conference will be available for 30 days for attendees.

The ECCE Technical Program Committee managed a larger team this year consisting of 27 track chairs and 179 topic chairs who organized and supervised the review process to identify the best papers for ECCE. We had two plenary virtual meetings in April to finalize all paper decisions, and more in July and September to decide on the final program. The conference received a total of 1576 digest submissions from 62 countries. After a rigorous peer review and scheduling process, 892 papers are scheduled for presentation. On average, each digest received over 4 reviews. Our gratitude goes to the valued track chairs, topic chairs and to the generous 1650 reviewers who made all this possible.

The tutorials co-chairs received and reviewed 50 proposals and selected 17 tutorials to offer online this year. We are also proud of offering 24 special sessions on various topics.

*We look forward to virtually welcoming you to ECCE 2021—thank you for helping us keeping the ECCE community connected!*

ECCE 2021 Technical Program Committee

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Michael Harke
Gianmario Pellegrino
Elisabetta Tedeschi
Mark Scott
Luca Zarri
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Zhen Xin, Hebei University of Technology, China
Harish Sarma Krishnamoorthy, University of Houston, USA
Mahshid Amirabadi, Northeastern University, USA
Óscar Lucia, University of Zaragoza, Spain

Conflict of Interest

Vice Chair: Andrea Cavagnino, Politecnico di Torino, Italy
<table>
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<tr>
<th>Time</th>
<th>Virtual 1</th>
<th>Virtual 2</th>
<th>Virtual 3</th>
<th>Virtual 4</th>
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<tr>
<td>9:00AM-9:45AM</td>
<td><strong>TUTORIAL 9AM1</strong> Photovoltaic Systems - From Basics to Advanced Grid Supportive Control</td>
<td><strong>TUTORIAL 9AM2</strong> Pulse-Width-Modulation: with Freedom to Optimize EMI</td>
<td><strong>TUTORIAL 9AM3</strong> A MATLAB/Simulink Approach of Photovoltaic Power Systems: Designing, Modeling, Simulation, and Control</td>
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<td>10:00AM-10:45AM</td>
<td><strong>TUTORIAL 10AM1</strong> Emerging Bidirectional Switches and Their Impact on Future AC Power Converters and Applications</td>
<td><strong>TUTORIAL 10AM2</strong> Interaction Among the Grid-connected Converters through Their Synchronization Mechanism</td>
<td><strong>TUTORIAL 10AM3</strong> Wide Bandgap Power Electronics Based Electric Machine Drives</td>
<td><strong>TUTORIAL 10AM4</strong> Monitoring Power Module Degradation via Lifetime-Varying Parameters</td>
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<td>11:00AM-11:45AM</td>
<td><strong>TUTORIAL 11AM1</strong> Advances in Intelligent Solid-State DC Substations for Future Interconnected DC Grids</td>
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<td><strong>TUTORIAL 11AM3</strong> Optimised Electrical Machine Designs for E-Mobility Applications</td>
<td><strong>TUTORIAL 11AM4</strong> Conducted, Near-field &quot;and Radiated EMI Emission Mitigation for Wide Bandgap Converters: Fundamentals, Modeling and Solutions</td>
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<td>11:45AM-12:00PM</td>
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<td>12:00PM-12:45PM</td>
<td><strong>TUTORIAL 12PM1</strong> Applying Artificial Intelligence to Battery State Estimation</td>
<td><strong>TUTORIAL 12PM2</strong> Resiliency-Oriented Grid-Interactive Converters: Concepts, Design, and Field Implementation</td>
<td><strong>TUTORIAL 12PM3</strong> Cryogenic Power Electronics Design for Electrified Aircraft Propulsion</td>
<td><strong>TUTORIAL 12PM4</strong> Hybrid Semiconductor Switches based Power Modules, Converters, and Systems</td>
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<td>12:45PM-1:00PM</td>
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<td>1:00PM-1:45PM</td>
<td><strong>TUTORIAL 1PM1</strong> Design and Development of Scalable Battery Testers/Emulators and Their Applications for Future Transportation Electrification</td>
<td><strong>TUTORIAL 1PM2</strong> Printed Circuit Boards in Power Converter Applications: Design Considerations and Failure Mechanisms</td>
<td><strong>TUTORIAL 1PM3</strong> Defining, Modeling, and Optimizing for Energy Efficiency in 5G</td>
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</tbody>
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Nearly 900 Technical Sessions available for flexible viewing to best accommodate your schedule.
### Monday, October 11, 2021

**Virtual 1**

- **PLENARY SESSION**
  - Motor Technology Selection and System Level Optimization Effects in Drive Systems
    - Dr. Konstantinos Laskaris
    - Principal Motor Designer, Tesla
  - Electric Aircraft: From Concept to Reality
    - Roei Ganzarski
    - CEO, magniX
  - Hybrid Electric Systems for the Commercial Aviation Sector
    - Christine Andrews
    - Hybrid Electric Systems Leader, GE Aviation
  - Driving Digital Transformation
    - Dr. Irene J. Petrick
    - Senior Director of Industrial Innovation in the Internet of Things Group, Intel

**Virtual 2**

**Virtual 3**

**Virtual 4**

<table>
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<th>All In Pacific Daylight Time</th>
<th>Virtual 1</th>
<th>Virtual 2</th>
<th>Virtual 3</th>
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<tbody>
<tr>
<td>8:30AM-10:30AM</td>
<td><strong>PLENARY SESSION</strong></td>
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<tr>
<td></td>
<td>Motor Technology Selection and System Level Optimization Effects in Drive Systems</td>
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<td>Dr. Konstantinos Laskaris</td>
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<td>Driving Digital Transformation</td>
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<td>Dr. Irene J. Petrick</td>
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<td>12:30PM-2:00PM</td>
<td><strong>SS16</strong> Coming Soon: Medium- and High-Voltage Gallium Nitride Power Devices</td>
<td><strong>SS17</strong> Power Electronics-Based Technologies for Grid Stabilization: Grid-Forming Inverters, Control of Inverter-Based Resources (IBRs), and Advanced Testing of IBRs</td>
<td><strong>SS10</strong> Energy Access and Empower Billions of Lives: Technologies, Impact and Opportunities for PELS</td>
<td><strong>SS25</strong> Power Electronics Enabled Power System with High Penetration of Renewables</td>
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## Schedule-at-a-Glance

### Tuesday, October 12, 2021

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<tr>
<th>ALL IN PACIFIC DAYLIGHT TIME</th>
<th>Virtual 1</th>
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<td>8:30AM-9:00AM</td>
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<td>PRODUCT SESSION: STMICROELECTRONICS</td>
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<td>Evolution of Power Delivery for Cloud Computing</td>
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<td>9:00AM-9:30AM</td>
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<td>PRODUCT SESSION: OPAL-RT</td>
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<td>HIL Demo of Solar Inverters</td>
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<td>Don't forget to check out the student demonstrations!</td>
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<td>2:00PM-3:30PM</td>
<td>SS24</td>
<td>SS20</td>
<td>SS6</td>
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<td>PRODUCT SESSION: GeneSic</td>
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<td>G3™ SiC MOSFETs, Unparalleled Performance and Robustness</td>
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<tr>
<td>8:30AM-10:15AM</td>
<td>SS1 Cybersecurity for Power Electronics</td>
<td>SS3 “ENSURE” Meets the World” the German Strategic Initiative ENSURE Presents Its Energy Outcomes</td>
<td>SS4 Power Electronic Technologies for Distributed Energy Resources</td>
<td>SS5 Wide-Bandgap Bidirectional Switches and the Applications They Enable</td>
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## Schedule-at-a-Glance

**Thursday, October 14, 2021**

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<tr>
<td>9:00AM-10:30AM</td>
<td><strong>SS2</strong> Energy Storage for Grid of the Future: Emerging Technologies, Applications and Trends</td>
<td><strong>SS8</strong> Thermal Design and Control for High Reliability Power Electronics, Electrical Drives, and Batteries</td>
<td><strong>SS13</strong> Standard Development and Industry Engagement Update from IEEE Power Electronics Society</td>
<td><strong>SS23</strong> EMI and Insulation Related Challenges and Solutions for WBG-based Power Electronic Systems</td>
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<tr>
<td>10:30AM-12:00PM</td>
<td><strong>SS2</strong> Energy Storage for Grid of the Future: Emerging Technologies, Applications and Trends</td>
<td><strong>SS12</strong> Advanced Design and Manufacturing Techniques for Electric Machines - Simulation and Test</td>
<td><strong>SS21</strong> P2964 IEEE Standard for Datasheet Parameters and Tests for Integrated Gate Drivers</td>
<td><strong>SS18</strong> Additive Manufacturing for Electrical Machines and Power Converters Design</td>
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<tr>
<td>12:00PM-1:30PM</td>
<td><strong>SS19</strong> Experimental Verification versus Simulation</td>
<td><strong>SS14</strong> Additive Manufacturing for Electric Machines</td>
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### AWARDS
Watch the Awards video and congratulate your colleagues using the Chat feature.

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**Everything You Need for Power Hardware-in-the-Loop**

Building a quality PHIL setup requires components to be carefully selected not just for their technical capability but also for their inter-compatibility. With the Microgrid PHIL Test Bench, OPAL-RT has taken the guesswork and risk out of PHIL with a turnkey product that offers one of the highest performance and versatile setups in the market.
Motor Technology Selection and System Level Optimization Effects in Drive Systems
Dr. Konstantinos Laskaris
*Principal Motor Designer, Tesla*

True optimal design constitutes an important competitive advantage in electric vehicles and requires good knowledge of physics modeling, parametric design, numerical simulations, and decision making. Battery, Motor, Inverter and Gear design space is searched during the optimization process. The efficiency and mass of the resulting powertrain affect the total cost, depending on the application. Powertrain compaction is key objective, but it comes with reduction in system efficiency and in many cases, at higher overall cost. Moreover, higher speed, more compact systems, exhibit dominant high frequency losses, introducing the need for advanced modeling to capture the phenomena. This keynote outlines key characteristics of motor, inverter and gears to achieve optimal design with particular focus on the motor technology.

Bio: Dr. Konstantinos Laskaris was born in Athens, Greece, received his diploma in Electrical and Computer Engineering from the National Technological University of Athens (NTUA), his master’s degree in Signal Processing from the Imperial College London, UK, and his PhD in Electric Motor geometry optimization for variable speed drives from the NTUA, Greece. Since 2012, Dr. Laskaris has been the Chief Motor Designer at Tesla Motors, located in the Silicon Valley, California, where he leads the team of motor design engineers. Some of his most significant projects at Tesla include the drive unit system design and optimization for the Model S, Model X, Model 3, Model Y and Semi-Truck vehicles. His research interests include parametric design and loss modeling of synchronous and asynchronous machines using finite element analysis, as well as development of multi-objective optimization methods using supercomputers. Dr. Laskaris has also worked in education, as a laboratory partner in NTUA, teaching the science of electric machines and is a co-founder of the Prometheus team in NTUA, which participates in EV fuel economy contests and holds the Panhellenic fuel consumption record today.
**Electric Aircraft: From Concept to Reality**

Roei Ganzarski  
**CEO, magniX**

There are multiple companies and programs around the world pursuing electric aviation. From pure battery electric, to Hydrogen electric, to hybrid, these programs are mostly run by new entrants into the aviation industry, with some programs also being introduced by the incumbents. We will review from a new entrants perspective, what it really means to take electric propulsion and aircraft from concept to reality including challenges, pitfalls, and successes. What practical real-world lessons should be considered when taking on such an audacious goal.

Bio: Roei is CEO of magniX, an electric aviation propulsion company. With a vision of connecting communities with low-cost, clean air transportation, magniX is disrupting aviation as we know it. Roei is also executive chairman of Eviation, the electric aircraft OEM bringing a newly designed all-electric aircraft to market. Prior to magniX, Roei was CEO of BoldIQ - a provider of dynamic real-time scheduling optimization software. Under Roei’s leadership, BoldIQ grew from seed software startup to multi-million-dollar profitable SaaS company. Before BoldIQ, Roei was with the Boeing family of companies in continuously increasing roles of responsibility. His last role was Chief Customer Officer for Boeing’s Flight Services division where he led worldwide customer and market facing organizations and was responsible for revenue growth and customer service. Other experiences prior to Boeing include investment banking, corporate finance, advertising, and the military. He is a graduate of Wharton’s Advanced Management Program, earned an MBA from the University of Washington, and a BA in Economics from The University of Haifa. Roei lives with his family in Redmond, Washington, USA.

**Hybrid Electric Systems for the Commercial Aviation Sector**

Christine Andrews  
**Hybrid Electric Systems Leader, GE Aviation**

GE Aviation is committed to a more sustainable future of flight. One of the enabling technologies the jet engine maker is pursuing to help the aviation industry reach its decarbonization goals is hybrid electric capability for single-aisle aircraft. Single-aisle air transport is the largest civil aviation market, where emissions-reducing technologies would have a major impact. In this presentation, GE Aviation will provide an overview of the challenges and opportunities for making hybrid electric systems a reality for this commercial aviation sector and the integration of motors and generators with gas turbine engines, electrical power distribution systems, electrical power converters, electricity storage and more.
Christine is the Hybrid Electric Systems leader for GE Aviation, responsible for the advancement of all power electronics technology development and integration with the gas turbine. Previously, Christine served as the Business Program Manager for the Aviation business at GE Research, where she evaluated future technologies and developed relevant aviation technologies from supporting next generation platforms to servicing existing fleet to improve revenues.

Christine has been at GE for 8 years, and has held various leadership positions across many disciplines within aviation engineering that have yielded many technology advancements in both the combustor and augmentor modules. She has an excellent track record of establishing and maintaining strong customer relationships by consistent execution of government programs. Prior to joining GE, Christine held various engineering positions at Gulfstream Aerospace.

Monday, October 11 10:00AM-10:30AM

Driving Digital Transformation
Dr. Irene J. Petrick
Senior Director of Industrial Innovation in the Internet of Things Group, Intel

Industry 4.0 harnesses digital tools to make industrial operations smarter, more efficient, and ultimately to operate autonomously. At the heart of this transformation lies data and its ability to drive proactive decisions. To accelerate the digital transformation journey you need both a long term vision and a digital architecture. It’s not just applying digital tools to current operations. Instead, successful companies have had to rethink complex interactions between people, processes, organizational culture and technology. This presentation highlights lessons learned during Intel’s three year study of over 500 people at over 400 companies.

Bio: Dr. Irene J. Petrick joined Intel in 2015 and is Senior Director of Industrial Innovation in the Internet of Things Group. Irene focuses on emerging technology, social, and global trends and their combined impact on the industrial space. Her work highlights the industrial internet of things, edge computing, the transition to intelligent manufacturing and the needs of the future workforce, 3D printing and distributed manufacturing and the new business models that are enabled by intelligent manufacturing. Prior to joining Intel, Irene was a professor at Penn State and has been actively engaged with companies in their innovation and technology strategies for over 25 years, including work with twelve Fortune 100 companies, the U.S. military, and a wide variety of small to medium sized enterprises. Petrick is author or co-author on more than 200 publications and presentations.
Special Sessions

These presentation-only sessions are focused on timely and practical topics in the field.

**Wednesday, October 13 | 8:30AM-10:00AM | 10:00AM-12:00PM**

**SS1 | Cybersecurity for Power Electronics**

**SESSION ORGANIZERS:**

Prof. Alan Mantooth, *Distinguished Professor, The Twenty-First Century Research Leadership Chair in Engineering, University of Arkansas, USA*

Prof. Frede Blaabjerg, *Danish Professor and Villum Investigator, Aalborg University, Denmark*

Prof. Sudip K. Mazumder, *Professor, University of Illinois at Chicago*

The growing threat of cyber-physical attacks targeting electric power grids is rising in number and sophistication. This special session covers several aspects of trending secure power electronic design, intrusion detections, and resilient control schemes. The concept of cyber resiliency in the realm of power electronics at the system level will be presented. The special session hosts demonstrate the importance of designing power electronics with security features in mind in the context of increasingly connected power electronics as a result of IoT, Industry 4.0, and 5G. Device-level attacks that aim to compromise the controllers, intentional noises and denial of service will be presented considering their impact and potential mitigation approaches. Subsequently, this special session presents the significance of the power electronics at the device-level resiliency as it supports a system-level resilience framework, targeting the new trend of securing the edge following the “resilience by design” principle, and an approach for combining fault-tolerance techniques with cyber-attack surface diversification to make legacy real-time control systems resilient against classes of attacks will also be discussed. More importantly, this session will present several industry-oriented topics (e.g., standardization, HVDC applications, among others), covering the latest development of DER community in the areas of stakeholder education programs, standards development, and cybersecurity research.

**SPEAKERS AND PRESENTATIONS:**

> **Cybersecure Power Electronics – Why You Should Care**  
  Alan Mantooth, *Distinguished Professor, The Twenty-First Century Research Leadership Chair in Engineering, University of Arkansas, USA*

> **On Resiliency of Power Electronics Against Cyber Attacks**  
  Frede Blaabjerg, *Danish Professor and Villum Investigator, Aalborg University, Denmark*

> **Control Resilience and Cybersecurity Analytics of Power Electronics Dominated Grids**  
  Sudip K. Mazumder, *Professor*  
  Mohammad Shadmand, *Assistant Professor, University of Illinois Chicago*

> **Power and Energy Programs at the US National Science Foundation**  
  Aranya Chakrabortty, *NSF Program Manager*

> **Cyber Attack Resilient High Voltage Direct Current (HVDC) Systems**  
  Reynaldo Nuqui, *Senior Principal Scientist, Hitachi-ABB Power Grids*

> **DER Cybersecurity Stakeholder Engagement, Standards Development, and EV Charger Penetration Testing**  
  Jay Johnson, *Principal Member of Technical, Sandia National Laboratories*

> **The Role of Power Electronics in Edge Resiliency**  
  Salam A Baniahmed, *Lead Engineer, Eaton Corporation*
SS2 | Energy Storage for Grid of The Future: Emerging Technologies, Applications and Trends

SESSION ORGANIZER:
Dr. Tu Nguyen, Sandia National Laboratories

As the electric grid is rapidly transforming to be more renewable and distributed, there are significant technical issues imposed on the grid due to the highly variable renewable generation (e.g., wind and solar). Furthermore, the increasing threats of natural disasters and cyber/physical attacks have created a significant need to improve the resilience and reliability of current grid infrastructure. Grid energy storage systems (ESSs) can be a flexible grid asset that can help mitigate those issues by providing multiple services to grid operators, utilities, and end-users.

Even though the application space for grid energy storage has grown rapidly over the last few years, there are multiple challenges that need to be addressed in order to further facilitate the incorporation of ESSs in the grid. Therefore, this special session gathers the experts in this field to provide an overview and updates on emerging challenges, recent technologies, applications, and trends in the energy storage area. The information provided in this panel will benefit not only the industry but also other key stakeholders such as policymakers, project developers, and researchers in this area.

SPEAKERS AND PRESENTATIONS:

> Opening Remark: Energy Storage: Key Component of The Future Grid
Imre Gyuk, U.S. Department of Energy, Office of Electricity, Energy Storage Program Manager

> Energy Storage Standards Development
Charlie Vartanian, Senior Technical Advisor, Pacific Northwest National Laboratory

> Cold Storage - Making Energy Storage Work in the Far North
Jim McDowall, Business Development Manager

> Enabling Energy Storage for Grid Applications Through Advanced Power Electronics
Jacob Mueller, Senior Member of Technical Staff, Sandia National Laboratories

> Long-Duration Energy Storage: Emerging Technologies and Applications
Erik Spoerke, Energy Storage Materials Lead, Sandia National Laboratories

SS3 | “ENSURE” Meets the World: the German Strategic Initiative ENSURE Presents Its Energy Cosmos

SESSION ORGANIZERS:
Prof. Dr. Marco Liserre, Christian-Albrechts-Universität zu Kiel (Kiel University)
Maximilian Dauer, Siemens AG

In 2050, the German power generation will mostly rely on renewable sources such as wind and PV and will face a variety of new electrical consumers such as electric vehicles, which requires a restructuring of the entire energy grid. In the German strategic project “New ENergy grid StructURes for the German Energiewende - ENSURE” partners from industry, academia and civil society are developing a holistic solution for the future German energy grid called “Energy cosmos ENSURE” based on new technological concepts, such as sector coupling, innovative power electronics-based assets and profound ICT-integration and automatization, which fit in the actual social-economic framework. Along the way, a digital twin of the entire system is built for co-simulation and advanced testing purposes and selected pilot plants are installed in northern Germany to demonstrate the systematic interaction of the novel
assets, control and protection strategies in the “Energy cosmos ENSURE”. In the first part of the special section the challenges and conceptual solutions of ENSURE will be presented including: Power Electronic Transformer, MVDC grid coupling, dynamically meshed operation of hybrid distribution grids, and Co-Simulation as advanced testing facility for large grid infrastructure projects. The second part is dedicated to international strategic projects to expand the vision of future power grids to a worldwide perspective, including topics such as Hybrid AC/DC networks in the US, new HVDC technologies in China and soft-open points and DC links in the distribution network in UK.

SPEAKERS AND PRESENTATIONS:

> **Unlocking the Hidden Capacity of the Electrical Grid through Power Electronics**  
  Marco Liserre, *Kiel University*

> **High Power Charging System with Power Electronic Transformers**  
  Stephan Rupp, *Maschinenfabrik Reinhausen*

> **Flexibility in Distribution Grids with Medium-Voltage Direct Current (MVDC) - Technology and Use Cases**  
  Javier Iglesias, *Hitachi ABB Power Grids*

> **Evaluation of Dynamically Meshed Network Topologies for Improved Power Flow Allocation and Network Capacity Enhancement**  
  Silas Reigardt, *SW Kiel Netz GmbH*

> **Co-Simulation Test Bench for Grid Integration of Power Electronics Under Usage of Power-Hardware-in-the-Loop**  
  Frank Jungnickel, *Siemens AG*

> **Hybrid HVDC and HVAC Networks with Hybrid Substations for a Carbon-neutral Grid by 2050**  
  Johan Enslin, *Clemson University*

> **Innovation of HVDC Technology to Support the Power Grid to Integrate More Renewable Energy**  
  Shukai Xu, *China Southern Power Grid*

> **Back-to-Back Converters and DC links in UK Distribution Networks**  
  Tim Green, *Imperial College London; Jun Liang, Cardiff University*

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**Wednesday, October 13 8:30AM-10:00AM | 10:00AM-12:00PM**

**SS4 | Power Electronic Technologies for Distributed Energy Resources (DERs)**

SESSON ORGANIZERS:

*Liuchen Chang, University of New Brunswick*

*Sonny Yaosuo Xue, Oak Ridge National Laboratory*

*Hanphu Le, UC San Diego*

*Sudip Mazumder, University of Illinois Chicago*

*Minjie Chen, Princeton University*

*Yongheng Yang, Zhejiang University*

*Gab-Su Seo, National Renewable Energy Laboratory*

*Xiaonan Lu, Temple University*

*Jin Wang, Ohio State University*

*Prasad Enjeti, Texas A&M University*

*Juan Balda, University of Arkansas*

*Xiongfei Wang, Aalborg University*

*Ke Ma, Shanghai Jiaotong University*

*Jose Fernando Jimenez Vargas, Los Andes University*
This special session will present a comprehensive overview of the state-of-the-art technologies of power electronics for distributed energy resources (DERs). The topics and their contents include:

*Introduction to Distributed Energy Resources*: DER definitions and values to electric grids, market drivers (including climate change, energy transformation, regulatory policies), world DER market growth in terms of the revenue and capacity, DER grid interconnection requirements and standards, DER grid interoperability requirements and standards, and evolving DER technology trends.

*Integrated Power Components and Subsystems*: Power semiconductor devices: their roles and types including SiC and GaN, photoconductive semiconductor switches based on wideband gap devices, power semiconductor device modules and reliability, passive components, storage technologies, power management, integrated power circuits, power-systems-on-chip, and packaging.

*Power Conversion for DERs*: Overview of the power electronics technologies and converter-level roadmaps for distributed energy resources, including the roles and requirements of power electronics for DER systems, and design and implementation of future DER systems including solar photovoltaic, wind energy, charging infrastructure, and grid-scale energy storage, with focus on power electronics technologies featuring high efficiency, high power density, and advanced functions that are needed to support the future grid.

*Integration and Control of DERs*: Summary of the recent developments in integration and control of DERs, covering the state-of-the-art DER technologies for grid integration and control including power system support functions from DERs, control of individual DERs including grid-forming inverter controls, stability of power systems with inverter-based resources, microgrids and networked microgrids, and protection with a high level of converters for distribution and transmission systems.

*Security, Protection and Resilience for DERs*: Cyber security at the device level and system level, protection (including solid-state protection), reliability, safety, grid system restoration, resiliency-oriented controls, and communication protocols.

*MV and HV Technologies for DERs*: medium-voltage (MV) and high-voltage (HV) power electronic interfaces for distributed energy resources, including the following main topics: energy storage systems (ESS), PV farms and hybrid PV-ESS, wind farms, solid-state transformers, DC networks, and fast chargers for electric vehicles.

*Testing and Validation*: Overview of grid emulation technologies including the hardware-in-the-loop testing methods, along with the challenges and prospects in the end.

**SPEAKERS AND PRESENTATIONS:**

- **Introduction to Distributed Energy Resources, and their Market & Standards**
  - Liuchen Chang, Professor, University of New Brunswick
  - Sonny Yaosuo Xue, Oak Ridge National Laboratory

- **Integrated Power Components and Subsystems**
  - Hanh-Phuc Le, Assistant Professor, UC San Diego
  - Sudip Mazumder, Professor, University of Illinois at Chicago (UIC)

- **Power Conversion for DERs**
  - Minjie Chen, Assistant Professor, Princeton University
  - Yongheng Yang, Professor, Zhejiang University

- **Integration and Control of DERs**
  - Gab-Su Seo, National Renewable Energy Laboratory
  - Xiaonan Lu, Assistant Professor, Temple University

- **Security, Protection and Resilience for DERs**
  - Jin Wang, Professor, Ohio State University
  - Prasad Enjeti, Professor, Texas A&M University

- **MV and HV Technologies for DERs**
  - Juan Balda, Professor, University of Arkansas
SS5 | Wide-Bandgap Bidirectional Switches and the Applications They Enable

SESSION ORGANIZERS:

Dr. Thomas M. Jahns, University of Wisconsin – Madison
Dr. Victor Veliadis, North Carolina State University

Monolithic bidirectional switches hold the potential to trigger a revolution in the future of power electronics technology. Unfortunately, an impressive catalog of high-performance power converter topologies designed to use bidirectional switches has never achieved marketplace success for the lack of commercially available monolithic BD (M-BD) switch devices. No silicon-based M-BD switch technology has emerged that has successfully crossed the threshold into large-scale production. New wide-bandgap power device technology using GaN and SiC has opened intriguing avenues to WBG-based M-BD switches that hold much higher promise for overcoming the barriers to commercialization. Both lateral and vertical M-BD device topologies have been proposed using GaN and SiC that have resulted in prototype devices with ratings as high as 1400V and 100A. The purpose of this special session is to showcase promising state-of-the-art WBG-based M-BD switch technology in a manner that objectively evaluates both their strengths and technical challenges. This session also highlights some of the most promising applications for this prospective new generation of M-BD switches as well as the most likely power converter topologies that will take the fullest advantage of their availability. These application areas cover a wide spectrum extending from ac solid-state circuit breakers to static power converters to motor drives.

SPEAKERS AND PRESENTATIONS:

> WBG-based Solid-State-Bidirectional-Circuit-Breakers: Device Technology, and Opportunities and Barriers to Mass Market Adoption
  Victor Veliadis, Chief Executive & CTO, PowerAmerica

> Monolithic SiC-based Bidirectional FET (BiDFET): Exploring Opportunities & Challenges
  Subhashish Battacharya, Professor, North Carolina State University
  Dr. B. Jayant Baliga, Professor, North Carolina State University

> Bidirectional Power Semiconductor Switches: Challenges and Opportunities
  John Shen, Professor, IIT

> How Solid-State Circuit Breakers Enable the Energy Transition and How WBG Semiconductors Play a Critical Role
  Ryan Kennedy, CEO, Atom Power

> Solid-State Circuit Breaker: Opportunities and Challenges
  Xiaoqing Song, Sr. Research Scientist, ABB US Corporate Research Center

> Monolithic Bidirectional Switches - X-Technology of 3-Phase AC/DC Mains Interfaces
  Johann Kolar, Professor, ETH Zurich

> The Re-Emergence of Current-Source Inverters in Future Machine Drives Enabled by WBG-Based Bidirectional Switches
  Thomas M. Jahns, Professor, University of Wisconsin – Madison

> Power Scaling of Current-Source Inverter Technology with WBG-Based Bidirectional Switches to 100 kW for Electric Vehicle Applications
  Bulent Sarlioglu, Assoc. Professor, University of Wisconsin – Madison, WEMPEC
SS6 | Energy Storage Systems: Applications, Control and Interfaces

SESSION ORGANIZER:
Juan Carlos Balda, Professor, University of Arkansas

Power systems are rapidly evolving from few large generating stations into many distributed generating stations ranging from several megawatts to few kilowatts. Higher penetrations of distributed generation are leading to system operating modes not experienced in traditional power systems, for example, intermittent distributed generation and bidirectional power flows. Energy storage systems making use of power electronic interfaces complement intermittent distributed generation and may also provide services like reducing peak demands, particularly in constrained distribution systems, and frequency regulation. Additionally, energy storage is the enabling technology for green transportation, including electric vehicles. Governments are enacting regulations to accelerate the deployment of these systems. This special session will focus on energy storage systems by bringing speakers from different points of view; in particular, government, electric utilities, manufacturers, and academia.

SPEAKERS AND PRESENTATIONS:
> Special Session Outline and Introduction
  Juan Carlos Balda, University of Arkansas
>
> Power Conversion Challenges and Opportunities with Flow Batteries
  Paolo Piagi, Lockheed Martin
>
> Integration of Energy Storage Systems in Solar PV Systems
  Francisco D. Freijedo, Huawei Nuremberg
>
> Design and Evaluation of High Capacity Lithium-ion Battery Energy Storage Systems
  Rui Li, Shanghai Jiao Tong University
>
> Energy Storage Power Electronic Systems Integration Research at ORNL
  Michael Starke, Oak Ridge National Laboratory

SS7 | Advanced Power Electronics Integration for Renewables

SESSION ORGANIZERS:
John Seuss, United States (US) Department of Energy (DOE)
Suman Debnath, Oak Ridge National Laboratory (ORNL)

As hybrid resources (like photovoltaic [PV]) and energy storage systems [ESS]) are integrated into the grid and the interconnection standards are upgraded, it is important to understand newer power electronic topologies that can be utilized to reliably integrate these resources like providing advanced grid services. With the increasing maturity shown by silicon carbide (SiC) devices and their corresponding adoption in certain sectors (like industrial drives), there is a need to explore the next-generation power electronics topologies that can utilize the SiC devices to integrate hybrid resources and provide fast/efficient grid services. In this talk, several ongoing research efforts will be discussed to discuss these newer integration approaches of SiC devices and the corresponding advanced control functionalities that they can introduce.

SPEAKERS AND PRESENTATIONS:
> Overview of Solar Energy Technologies Office (SETO) and Funding Efforts in Power Electronics
  John Seuss, United States (US) Department of Energy (DOE)
> **Multi-port Autonomous Reconfigurable Solar Power Plant (MARS) - Next Generation Hybrid PV-ESS Plant with Integrated Services**  
  Suman Debnath, *Oak Ridge National Laboratory*  
  Jiuping Pan, *Hitachi ABB Power Grids Research*  

> **A Cascaded Power Electronics Architecture for Transformerless Medium-voltage PV Systems**  
  Brian Johnson, *National Renewable Energy Laboratory*  

> **M4 Inverter: An enabling technology for utility scale PV plus storage integration**  
  Alex Q. Huang, *University of Texas at Austin*  

> **Power Converter Architectures for Utility-scale Combined Solar Photovoltaic and Battery Storage Systems**  
  Giri Venkataraman, *Wisconsin Electric Machines and Power Electronics Consortium*  
  Mahima Gupta, *Portland State University*  

> **All SiC High Power Converters for Combined Integration of Solar PV and Energy Storage**  
  Yue Zhao, *University of Arkansas*  

> **Monolithic SiC-based Bidirectional FET (BiDFET): Exploring Opportunities and Challenges**  
  Subhashish Bhattacharya, *North Carolina State University*  

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**Thursday, October 14**  
9:00AM-10:30AM

**SS8 | Thermal Design and Control for High Reliability Power Electronics, Electrical Drives, and Batteries**

**SESSION ORGANIZERS:**  
Prof. Marco Liserre, *University of Kiel, Kiel, Germany*  
Prof. Rik W. De Doncker, *RWTH Aachen University, Aachen, Germany*

Temperature has a major effect on both batteries and power electronics (PE) performance and reliability. The development of the electromobility sector and the spreading of PE throughout society (e-mobility, industry, grid, consumer electronics, etc.), together with the trend towards increasing power- and energy- densities, and the rise of PE-based critical applications (more electrical aircraft, grid applications, etc.), therefore puts the spotlight on thermal management and reliability issues. Consequently, limiting peak temperatures, temperature gradients, and thermal cycling of power devices and batteries gains great relevance.

Limiting thermal stress can be achieved by combining high performance cooling technics (jet impingements, phase-change-materials, etc.) and temperature- and reliability- oriented control algorithms (active thermal control, loss reduction strategies etc.). At design stage, achieving high power density call for the use of improved modelling technics for complex and multi-physic systems. Furthermore, lifetime estimation and condition monitoring play an important part in reliability assessment. To reach these targets, high performance temperature measurement, imaging systems, and estimators are required during design and for field monitoring.

The industrial and academic speakers involved in this special session will tackle these issues with both conceptual- and application- oriented presentations. Altogether, they cover a broad area of expertise, including reliability of PE and batteries, thermal-guided design & control strategies, cooling technics, temperature sensing, imaging, and estimation, electromobility, and PE systems.

**SPEAKERS AND PRESENTATIONS:**

> **Design Challenges of High Power Density Dc-Dc Converters**  
  Rik W. De Doncker, Professor, *RWTH Aachen University*

> **Reliability Driven Control of Power Converter**  
  Marco Liserre, Professor, *University of Kiel, Kiel*
Special Sessions

> **Artificial Neural Network based Thermal Model Considering the Cross-Coupling Effects of Power Modules**  
Frede Blaabjerg, *Professor, Aalborg University*

> **State of the art Thermographic Cameras for Testing Power Electronics and Batteries**  
Stefan Kayser, *InfraTec*

> **Electro-thermal Co-Design of Traction Drive Inverters**  
H. Alan Mantooth, *Professor, Arkansas University*

> **Design of eAxle Propulsion Drives for Electric Vehicles**  
Jin Hwan Jung, *Hyundai Motor Company*

> **Influence of Thermal Gradients on Battery Performance**  
Florian Ringbeck, *RWTH Aachen University*

> **Experimental Thermal Analysis and Reduced Order Modelling of Direct Oil-Cooled PMSM**  
Henning Sauerland, *Hitachi Europe GmbH*

**Wednesday, October 13  2:00PM-3:30PM**

**SS9 | Advances in SiC and GaN Grid Applications to Support EV and Renewable Energy**

**SESSION ORGANIZER:**

**Dr. Victor Veliadis**, *Executive Director and CTO of PowerAmerica*

The power grid will soon need to accommodate a large EV charging infrastructure while at the same time incorporating more solar and wind energy sources. Panelists will address the following issues specific to medium voltage SiC technology in the context of grid capability:

- MV SiC MOSFET on-resistance, capacitance, and current ratings
- The design/modeling/fabrication of SiC Super junction (SJ) FETs and IGBTs
- Determine optimal SiC device for each grid application domain and device characteristics important to support the grid
- SiC SJ FETs and IGBTs in switching circuits
- Bipolar conduction induced defect generation is impacted by the higher current densities in SJ and IGBT devices

**SPEAKERS AND PRESENTATIONS:**

> **Co-Existence of GaN & SiC: Present and Future**  
Francois Hebert, *GLOBALFOUNDRIES*

> **The High and Low (Power) of SiC and GaN Transistor Applications**  
Tim McDonald, *Infineon Technologies*

> **Advances in Applications of SiC and GaN Technology**  
Rick Eddins, *GE Aviation*

> **Advances in GaN to Support EV and Renewable Energy**  
Larry Spaziani, *GaN Systems*

> **Design of a 6.6 kW Bidirectional On-Board Charger Using GaN with Integrated Driver, Protection and Temperature Reporting**  
Brent McDonald, *Texas Instruments*
Ensuring universal, affordable, and sustainable energy access is one of the biggest societal challenges of our time. As of 2020, close to a billion people worldwide live without having access to electricity, and another two billion have unreliable access. The centralized electric grid is not the optimal choice for remote and rural applications, due to environmental impact, cost, mismatch to user needs and challenges around financial feasibility. Decentralized approaches, such as solar home systems and microgrids, have emerged as a response to shortcomings of the centralized grid approach, but affordability, scalability, interoperability, societal and technical sustainability remain as key challenges. Power electronic technology is one of the key enabling technologies for context-appropriate and sustainable energy access solutions. The IEEE Power Electronics Society (PELS) engaged with Energy Access through organizing a global challenge - Empower a Billion Lives (EBL-I), and by including Energy Access as a new and core topic in its long-range planning. Following on the success of the first EBL-I round, a strong expression of interest in the technologies underlying energy access, and a burgeoning need for decentralized power systems with more autonomous control, the Global Energy Access Forum and the Technical Committee - 12: Energy Access was formed by PELS to provide global technical leadership in this important area.

SPEAKERS AND PRESENTATIONS:

> Segment 1: Welcome and Framing of Technology Opportunities and Issues leading to the formation of the Global Energy Access Forum and Empower a Billion Lives
Deepak Divan, Georgia Institute of Technology, USA – Welcome and Moderator of Segment 1

Three Panelists to address the topics of technology opportunities and issues:
1. Silard Liptak, Agsol, Kenya
2. Shreyas Kulkarni, Endeavour Energy, USA
3. Rajan Kapur, IEEE Smart Village, Larenkelo Ventures, USA

> Segment 2 - Empower a Billion Lives II - Global Competition to Crowdsourc Solutions to Energy Access
Jelena Popovic, University of Twente, The Netherlands (moderator) Empower a Billion Lives, PELS TC-12 Energy Access

Three Panelists to address the establishment of PELS TC-12 Energy Access and launching the Empower a Billion Lives -II
1. Issa Batarseh, University of Central Florida, Member PELS TC-12 Energy Access, Empower a Billion Lives, USA
2. Sanjib Kumar Panda, National University of Singapore, Member, PELS TC-12 Energy Access - Chair
3. Deepak Divan, Georgia Institute of Technology, USA, Steering Chair PELS Global Energy Access Forum
SS11 | Power Electronics Dominated Grids: Dynamic Modeling and Simulation for Reliable and Resilient Operation of Future Grids

SESSION ORGANIZERS:
Suman Debnath, Oak Ridge National Laboratory (ORNL)
Kemal Celik, United States (US) Department of Energy (DOE)

With increased penetration of power electronics based resources in the grid like photovoltaic (PV), energy storage systems (ESS), electric vehicle (EV) chargers, among others, there is a need to understand the impact on the reliability and resilient operation of future grids. Towards the same, next-generation tools and control methodologies are required for stable, reliable, and resilient operation of future grids. In this talk, the opportunities in future power grids with increased penetration of power electronics will be presented followed by the presentations on ongoing research activities in development of next-generation tools, models, and control functionalities.

SPEAKERS AND PRESENTATIONS:

> Collaborative Sensor Networks to Assist Data-driven PV Systems Dynamic Modeling
  Marissa Enid Morales-Rodriguez, Solar Energy Technology Office (SETO) from the US Department of Energy (DOE)

> High-Fidelity Electromagnetic Transient (EMT) Modeling of Power Electronics in Future Grid
  Suman Debnath, Oak Ridge National Laboratory

> Holistic Modeling Methods to Improve the Stability of Inverter-Dominated Power Grids
  Maozhong Gong, GE Research

> Dynamic Model Development of Inverter-Based Resources through Experiment Measurements and Real-World Event Data
  Lingling Fan, University of South Florida

> Dynamic Modeling and Fault Simulations of an IPRB Microgrid with Multiple Grid Forming Inverters
  Lisa Qi, ABB US Research Center

> Advanced Generic Dynamic Models for Screening of Reliability and Resilience Challenges of Future Grids
  Jens Boemer, Electric Power Research Institute (EPRI)

SS12 | Advanced Design and Manufacturing Techniques for Electric Machines – Simulation and Test

SESSION ORGANIZER:
Prof. David Lowther, Professor, McGill University

The session is intended to provide a series of presentations highlighting the industrial needs and processes for electrical machine design and manufacture and recent university research which is targeted at addressing these needs. The topics covered will range from the design process, as illustrated by the V-cycle approach, and including the multi-physics performance of a proposed motor-drive system; the use of additive manufacturing technologies to enable the implementation of machine topologies which cannot be constructed using conventional, mostly subtractive, manufacturing techniques; and the use of state of the art machine learning techniques to enhance and assist in the design of novel electrical machine architectures. Finally, while “digital twin” technology is driving simulation to new levels and, hopefully, reducing the number of prototypes needed, the physical implementation must be tested to verify the performance of the real device and the issues involved in fast and accurate testing will be discussed.
SPEAKERS AND PRESENTATIONS:

> **Fundamental Design Process of Common Electric Machines**
  James Hendershot, *MotorSolver LLC*

> **Multi-Physical Simulations in Electric Machine Design - Challenges and Opportunities**
  Tanvir Rahman, *Siemens Digital Industries Software*

> **Machine Learning Techniques for the Topology Optimization of Electrical Machines**
  David Lowther, *McGill University*

> **Additive Manufacturing of Complex Shape Hard Magnetic Materials for PM Machines**
  Pragasen Pillay, *Concordia University*

> **Fast, Accurate and Comprehensive Testing of Traction Machines**
  Narayan Kar, *University of Windsor*

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**Thursday, October 14**

**SS13 | Standard Development and Industry Engagement Update from IEEE Power Electronics Society**

SESSION ORGANIZERS:

**Johan Enslin**, Chair of PELSC, Clemson University

**Matt Wilkowski**, Vice chair of PELSC, EnaChip

**Xu She**, Secretary of PELCS, Carrier Corporation

IEEE power electronics society (PELS) is the driving force behind numerous standard activities and international technology roadmap initiatives relating to power electronics. With the motivation of providing our community the latest update of the standard development within IEEE PELS as well as promoting better involvement especially from industry, this special session brings together the leading experts who are actively leading the development efforts of power electronics standards. The topics span from component (capacitor, magnetics, etc.) level development to system level integration (grid forming inverter, etc.).

SPEAKERS AND PRESENTATIONS:

> **Activities of the IEEE PELS Standards Committee and Industry Engagement**
  Johan Enslin, *Professor of Clemson University and PELS VP of Standards*

> **Updating ETTC Standards for Magnetic Components to Keep Pace with Technology**
  George Slam, Senior Applications and Content Engineer Wurth Elektronik, Chairperson ETTC

> **Keeping IEC TC 51 Standards Relevant to Market Applications of Magnetics**
  Mark Swihart, Vice President of Technology and Product Development Magnetics division of Spang and Company

> **Impact of Near Magnetic Field Characteristics on Performance of Converters**
  Matt Wilkowski, Vice President of Magnetics Technology and Engineering EnaChip
  Fang Luo, *Director of Spellman High Voltage Electronics Laboratory Stoney Brook University*

> **Development of IEEE 2988: Recommended Practice of Use and Functions of Virtual Synchronous Machines**
  Qing-chang Zhong, *Professor, Illinois Institute of Technology*

> **Update on Grid-forming Inverters Working Group and Standard Development**
  Leo Casey, *Google X*
**Thursday, October 14**

**SS14 | Additive Manufacturing for Electric Machines**

**SESSION ORGANIZERS:**

**Franco Leonardi**, Ford Motor Company  
**Leyi Zhu**, Ford Motor Company

The special session will focus on what is currently available in terms of additive manufacturing solutions for electric machines, and also on what is coming in the near and far future.

**SPEAKERS AND PRESENTATIONS:**

- **Additive Manufacturing of Copper Hairpin Windings**  
  Jakob Jung, Additive Drives GmbH

- **Design Concepts for Electric Machines leveraging Additive Manufacturing**  
  Jagadeesh Tangudu, Raytheon Technologies Research Center

- **Additive Manufacturing of High Performance Stator and Rotor Structures for Electric Machines**  
  M. Parans Paranthaman, Oak Ridge National Lab

- **3D Printed Permanent Magnets: From Material Fundaments to e-Motor Applications**  
  Jaćim Jaćimović, ABB Switzerland

- **Rapid Development of Electric Machines - Casting with AM**  
  Keith Denholm, Grainger & Worrall

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**Wednesday, October 13**

**SS15 | Future of Wide-Bandgap Devices SiC, GaN and Diamond and Their Emerging Applications in Power Electronics**

**SESSION ORGANIZER:**

**Dr. Tanya Gachovska**, Solantro Semiconductor Corp.

The need for high-voltage devices operating at high frequencies and temperature is growing, especially for advanced power electronics. Si-based power devices has some limitations. They are not able to meet these requirements without connecting many devices in series and in parallel, using snubbers and expensive cooling systems. Thus, the market of Si power devices have started to decrease and wide band gap semiconductors have attracted considerable attention. Research into SiC, GaN, and diamond as materials for power devices has been carried out over the past two decades.

SiC, GaN and diamond have wide-bandgap energy resulting in higher breakdown strength for a given blocking voltage. Therefore, SiC, GaN and diamond devices have smaller drift layers or channel lengths as compared to Si devices. As a result, the storage of the minority carriers or the input and output capacitance and, therefore, the switching losses are reduced. This leads to an increase of the switching frequency high than 0.5 MHz, reducing power systems passive components size and cost. In the last 5 years, more companies manufacturing SiC and GaN have come to the market and new startup companies have arised. The price of SiC and GaN devices have decrease drastically and more application.

This special session will offer insights into the future and trends for SiC, GaN and diamond devices and their emerging applications in power electronics.
After two decades of relentless development, GaN power high-electron-mobility transists (HEMTs) have been commercialized in voltage classes up to 650 V. In the last few years, strong momentum has emerged in industry and academia to extend the application space of GaN devices into the medium-voltage applications. Several industrial companies are developing 650-1200 V lateral GaN HEMTs, either discrete devices or modules. For example, VisIC is developing 800-1200 V GaN HEMT modules for EV applications. Meanwhile, 600-1200 V GaN transistors based on the vertical architecture are being manufactured on 100-mm GaN-on-GaN platform by several companies in the U.S. and Japan. For example, NexGen Power Systems has demonstrated the production of 650-1200 V vertical GaN JFETs with avalanche capabilities; Toyoda Gosei has demonstrated 1200 V vertical GaN MOSFETs with over 100 A current. In academia, high-voltage GaN devices have been demonstrated up to 10 kV recently. All these progresses suggest that the industrial medium-voltage GaN devices will be available to power electronics engineers very soon. This special session provides a timely overview of the state-of-the-art medium- and high-voltage GaN devices and an industry-centric discussion on the benefits and applications spaces of these coming devices.

SPEAKERS AND PRESENTATIONS:

> **Unlocking the Full Potential of GaN in Power Systems**  
  Dinesh Ramanathan, Founder and Co-CEO, NexGen Power Systems

> **Development Status of Vertical GaN SBDs and MOSFETs**  
  Tohru Oka, Project General Manager & Senior Principal Engineer, Toyoda Gosei

> **Vertical Gallium Nitride Devices for Medium-Voltage Power Electronics**  
  Robert Kaplar, Manager of the Semiconductor Material and Device Sciences Department, Sandia National Laboratories.

> **650V Lateral GaN Devices and Modules for 400V and 800V EV Applications**  
  Tamara Baksh, CEO, VisIC Technologies

> **Healthcare Applications of GaN Power Devices**  
  Juan Sabate, Senior Principal Engineer, GE Global Research Center
SS17 | Power Electronics-Based Technologies for grid Stabilization: Grid-Forming Inverters, Control of Inverter-Based Resources (IBRs), and Advanced Testing of IBRs

SESSION ORGANIZERS:

**Jing Wang,** National Renewable Energy Laboratory  
**Andy Hoke,** National Renewable Energy Laboratory

Recently, power inverters with grid-forming capabilities have attracted broad interest because these inverters do not rely on external voltage sources to generate power, which pertains better stability and reliability than traditional grid-following DERs. Thus, research and development work on grid-forming inverter has extensively carried out in academia and industry. In this panel, we will first introduce the grid-forming inverter manufacture, ABB, to present their latest development in grid-forming battery inverters. Then, one researcher from Siemens will present their research work on performance comparison of different grid-forming control strategies. Apart from the grid-forming inverter related topic, power electronics control and hardware-in-the-loop is also covered. A senior researcher from NREL will demonstrate the operation of a transmission system (Maui in Hawaii) at and near 100% IBRs.

The professor from University of Alabama will share his latest research work on investigating many abnormal operations of IBRs and IBR plants and present an eye-opening discovery of the shortcomings of traditional dq control. In the end, the research engineer from NREL will present the advanced testing and validation of grid-connected inverters through power-hardware-in-the-loop simulation from small scale (single inverter) to large scale (100+) inverters. This panel will include power electronics-based technologies for grid stabilization, which will be informative, educational and insightful to learn the state-of-the-art and future directions of power electronics-based resources and systems.

SPEAKERS AND PRESENTATIONS:

- Development of Grid-forming Inverters for Supporting Robust and Reliable Future Grids  
  John Glassmire, Hitachi-ABB power Grids

- Performance Comparison of Parallel Grid-Forming Inverters  
  Amit Pandey, Siemens

- Operation of a Transmission Electric Power System At and Near 100% Inverter-based Resources  
  Andy Hoke, NREL

- Impacts of Equivalent Dynamic Grid Impedance and Dynamic Inverter P-Q Capability on Reliability and Harmonic Stability of Inverter Based Resources Plant  
  Shuhui Li, University of Alabama

- Advanced Power-Hardware-in-the-Loop Evaluation of Inverter-based Resources (IBRs)  
  Jing Wang, NREL
**SS18 | Additive Manufacturing for Electrical Machines and Power Converters Design**

**SESSION ORGANIZERS:**

Bulent Sarlioglu, Jean van Bladel Associate Professor, University of Wisconsin  
Ayman El-Refaie, Werner Endowed Chair, Marquette University  
Will Sixel, NASA Glenn Research Center in Cleveland

In aircraft electrification, increasing the specific power and efficiency of electrical components is critical to make more electric/hybrid/electric propulsion physically and economically feasible. Additive manufacturing enables unique geometries that conventional manufacturing techniques cannot achieve. Additively-manufactured applications in electric machines and power electronics include permanent magnets, shafts, and housing designs, thermal management systems, integrated motor drives, additively manufactured coils, and highly optimized traditional designs. Additive manufacturing techniques also allow for increased design flexibility and co-design of related components and subcomponents, allowing for greater system-level performance optimization.

**SPEAKERS AND PRESENTATIONS:**

> **Exploring Potential of Additive Manufacturing for Next Generation Electrical Machines and Power Electronic systems**  
  Peter de Bock, ARPA-E, US Department of Energy

> **Additive Manufacturing of Fe-Si Soft-Magnetic Alloys**  
  Alex Plotkowski, Oak Ridge National Laboratory

> **3D Printed Magnetic Cores for Electrical Machines**  
  Shanelle N. Foster, Assistant Professor, Department of Electrical and Computer Engineering, Michigan State University

> **Developing the Supply Chain for the Next Generation High-speed, High Voltage Synchronous Reluctance Motor**  
  Ozge Taskin, Ricardo

> **Additive Manufacturing of Next Generation Electrical Machine Windings**  
  Nick Simpson, Senior Lecturer, University of Bristol

> **Design of a Highly Saturated High-frequency Electric Machine with Additively Manufactured Coils**  
  Max Liben, Chief Technology Officer, H3X Technologies Inc.
A fundamental issue that is inherent in engineering work regards how we can verify our theoretical calculations. For some applications, prototyping is relatively convenient, and the experimental results are preferred as proof that the theory is correct, but in the motor and drives world, while some prototyping is possible—most of those cases involve smaller machines and lower power drives as well as less demanding measurement accuracy; but electric machines and drives testing generally become more expensive and time consuming as the machine and drive rating increases, which require massive resources in terms of hardware, software, and manufacturing expertise to conduct valid experiments with confidence. In this era of powerful computational capabilities, many simulations tools have developed to the point where the accuracy of the simulation results have grown and the time it takes to do these simulation calculations have minimized over the years. Complex analysis of interconnected systems can also be done in a timelier manner, and the development of HIL has made the simulation environment more flexible and more realistic. Ultimately, the question is whether the simulation results are trustworthy enough to be accepted as the proof of the proposed technical solution and design? Has the simulation software attained a level of accuracy which matches and/or surpasses the accuracy of experimental results?

SPEAKERS AND PRESENTATIONS:

Panelists:
Ayman EL-Refaie, Professor, Marquette University
Andy Knight, Professor, University of Calgary
Mike Degner, Ford
Joel Van Sicke, MathWorks
Sudipta Chakraborty, Director – Energy Systems, OpalRT
Takeshi Yamada, JMAG
Philippe Wendling, Altair

First session topics
> Discussion on testing accuracy (measurement, stackup, numerical specifications).
> Discussion on simulation accuracy (modelling errors, computation errors, stackup).
> How to determine testing accuracy.
> How to determine simulation accuracy.
> Calibration issues
> Uncertainties.

Second session topics
> Open discussion on open questions:
  • At what point can simulation results be considered adequate to testing during the intermediate steps of the R&D cycle? If ever?
  • At what point can simulations results be considered adequate to replace testing as the final proof of verification prior to manufacture, if ever?
  • At which stage during the R&D cycle should simulation results be adequate to push the R&D timeline forward?
  • How to determine the optimal way of employing simulation and experimentation in a product R & D cycle? In a research cycle?
  • Reviewer discretion: when should reviewers insist on experimental results?
SS20 | PV Inverter Reliability: Industry Status, Technical Gap, and Future Needs

SESSION ORGANIZERS:

Zheyu Zhang, Assistant Professor, Clemson University
Ramanathan Thiagarajan, National Renewable Energy Laboratory

Motivated by the fact that field data from PV power plant operators show that power electronics converter contributes most to operation and maintenance (O&M) events, responsible for between 43% and 70% of the service calls, it is essential to initialize a conversation focusing on the PV inverter reliability with a wide range of stakeholders’ participation. This could benefit the research community to better understand the industry status, technical gap, and future needs. In this panel, the audience will hear diverse opinions shared by five distinguished panelists from PV power plant operators and PV inverter manufacturers to U.S. DOE Solar Energy Technologies Office and National Renewable Energy Laboratory, and their visions to improve PV inverter reliability in the field. This panel will include the effects of PV inverter reliability on the overall energy yield of PV Power plants from a PV plant operator. This will be followed by presentations on the effects of PV inverter design on inverter reliability by two leading PV inverter manufacturers. Following this, speakers from DOE and NREL will describe the past and current efforts on inverter reliability and standards development work performed within the DOE space.

SPEAKERS AND PRESENTATIONS:

> Importance of Inverter Reliability on Operating PV Power Plants
  Nick de Vries, SVP of Technology and Asset Management, Silicon Ranch

> Solar Inverter Reliability: DOE-funded R&D and Future Directions
  Tassos Golnas, Technology Manager, U.S. DOE Solar Energy Technologies Office

> Insights into Reliable PV Inverter
  Daniel Clemens, Reliability Technical Manager, SMA Solar Technology

> Design of Reliability for PV Inverter
  Matt Ursino, Senior Reliability Engineering, YASKAWA Solectria

> Overview of IEC 62093 ed 2– The PV Inverter Qualification Test
  Peter Hacke, Senior Scientist, National Renewable Energy Laboratory

SS21 | P2964 IEEE Standard for Datasheet Parameters and Tests for Integrated Gate Drivers

SESSION ORGANIZER:

Dr. Tanya Gachovska, Solantro Semiconductor Corp.

Power electronics applications employ power switches. Every switch requires a gate driver, a power amplifier that receives a low-power input from a controller and produces a high-current driving output for the gate of high-power switches such as an IGBT, MOSFET, JFET, or HEMT. Some gate drivers have protection features such as fast short-circuit protection (e.g. DESAT), active Miller clamp, shoot-through protection, shutdown, and overcurrent protection, which make them well-suited for both silicon and wide-bandgap power devices.

However, it is difficult to compare the IC gate drivers using their datasheet parameters. Every company names the drivers’ pins and parameters with different approaches. The parameters are tested at different conditions and methodology or in most of the cases the conditions and the methodology are not given. Only some companies give the selected test circuits. IEEE-IAS-PEDCC has initiated a working group for a standard to provide datasheet parameters and tests for integrated gate drivers, which include
non-isolated gate drive, level-shifted gate drive, and isolated gate drive. The standard scope includes terminology, mnemonic, and pins’ description; parameters and definitions; and test methods and conditions to obtain the parameters. The special session will include an update on the working group.

SPEAKERS AND PRESENTATIONS:

> **Standardization of “Active Miller Clamp”**
  Wolfgang Frank, *Infineon Technologies in Munich/Germany*

> **Gate Driver Absolute Maximum Ratings**
  Zheyu Zhang, Assistant Professor, *Clemson University*

> **Why Do We Need a Standard for Gate**
  Cong Li, *General Electric*

> **Desaturation Protection Requirement**
  Inki Park, *ON Semiconductor*

> **Comparing Gate Driver Timing and Drive Strength Specifications**
  Ryan Schnell, *Analog Devices iCoupler*

> **Gate Driver Pin Naming Standard**
  Srivatsa Raghunath

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**Wednesday, October 13  2:00PM-3:30PM**

**SS22 | Grid Integration of Inverter-Based Distributed Energy Resources: Operation, Planning, and Guidelines**

SESSION ORGANIZERS:

- **Dr. Jianzhe Liu**, Argonne National Laboratory (ANL)
- **Dr. Kun Zhu**, Midcontinent Independent System Operator (MISO)
- **Dr. Jens C. Boemer**, Electric Power Research Institute (EPRI)
- **Dr. Reza Ghaemi**, General Electric Research (GER)
- **Dr. Xuan Wu**, American Electric Power (AEP)

The US power system will be undertaking an monumental transformation as it moves forward to being 100% clean energy powered by 2035. In the meantime, the extreme weather events and increasingly stressed loading conditions have put grid stability, reliability, and resilience at risk. The growing power electronics intensive inverter-based resources (IBRs) have a promising potential in contributing to the clean energy transformation while improving system performance. Challenges for IBRs grid integration include: 1) how to design stability guaranteed control for the power electronics interfaced resources that usually have low inertia and high stochasticity; 2) the grid planning issue of IBR could be significantly different from the conventional ones; 3) what the industrial guidelines for IBRs integration would be in the future as they have already undertaken significant changes; 4) how we should control a large-scale fleet of IBRs as the problem is high-dimensional and computationally challenging; and 5) how we should optimize the location of energy storage systems given their critical role in IBR’s grid integration and considering the numerous choice of location and capacity. This special session will provide useful industry insights into all the aforementioned issues.

SPEAKERS AND PRESENTATIONS:

> **Robust Optimal Power Flow with Stability and Feasibility Guarantees for Systems with Large-Scale IBR Integration**
  Jianzhe Liu, ANL

> **NERC SPIDER Working Group Update**
  Kun Zhu, MISO

> **State of The Art and Potential Improvements to Existing IBR Distribution Interconnection Practices & Studies**
  Jens C. Boemer, EPRI
Special Sessions

> Scalable Demand Side Control for High Renewable Penetration Distribution Grid: Solutions and Challenges
  Reza Ghaemi, GER

> Optimal Planning & Operations of Batteries in Distribution Systems to Enhance Reliability and Attain Market Revenues
  Xuan Wu, AEP

Thursday, October 14 9:00AM-10:30AM

SS23 | EMI and Insulation Related Challenges and Solutions for WBG –based Power Electronic Systems

SESSION ORGANIZERS:
Bulent Sarlioglu, Associate Professor, University of Wisconsin
Jin Wang, Professor, Ohio State University

Wide bandgap device-based power converters are expected to bring significant efficiency and power density improvements for a wide range of applications. Through the effort from both industry and academia, many circuit implementation and system-level related challenges for implementing WBG devices have been solved. But EMI and insulation degradation are still two significant concerns because of the high dv/dt and di/dt switching of WBG devices. Thus, the organizers of this proposed special session has invited speakers from NASA, industry and academia to present details of EMI and insulation related challenges and solutions.

SPEAKERS AND PRESENTATIONS:

> Reliability as a Barrier for More Electrification
  Isik C. Kizilyalli, the Associate Director for Technology at the Advanced Research Projects Agency - Energy (ARPA-E)

> Challenges of Megawatt Scale Electric Aircraft Propulsion
  Andrew Woodworth, Hybrid Electric Aircraft Materials Technical Lead, NASA Glenn Research Center

> Presentation Title: On Some Problems and Solutions Related to High Voltage in Aviation
  Thierry Lebey, High Voltage Team Leader, Safran

> Minimizing EMI Suppression Penalties in Motor Drive Applications using Wide-Bandgap Current Source Inverters
  Dr. Thomas M. Jahns, Professor, University of Wisconsin - Madison, WEMPEC

> EMI Noise Signatures of Si- vs. WBG-based Traction Inverters
  Chingchi Chen, Technical Leader, Ford Motor Company

Tuesday, October 12 2:00PM-2:30PM

SS24 | Booming the Blue Economy: A New Era for Wave and Hydrokinetic Energy

SESSION ORGANIZERS:
Dr. Yue Cao, Assistant Professor, Oregon State University
Dr. Jing Sun, Michael G. Parsons Collegiate Professor, Univ. of Michigan - Ann Arbor
Dr. Ted Brekken, Professor, Oregon State University; Co-Director, Pacific Marine Energy Center (PMEC)

The Pacific Northwest (including Oregon, Washington, Alaska, and British Columbia-Vancouver area), among other global coastal regions, has access to abundant renewable energy embedded in ocean and river. The energy, known in either a wave form (vertical motion) or a current form (horizontal motion), still
has limited power generation capacity to local grids due to several challenges, especially at the core of mechanical to electrical energy conversion. In 2019, the US Department of Energy (DOE) launched the Powering the Blue Economy initiative to explore the billions of dollars worth of such hydro energy potential alongside the coastline and riverine communities. This decade marks a new era for research and development to bring the highest efficiency, highest reliability, and lowest cost for such blue energy usage, enabling a wide range of adoption. In this session, four industry and one government panelists and three academia organizers will present and discuss the technology needs, innovations, and demonstrations of converter-level design, interdisciplinary control co-design, and system integration to the microgrid/grid connection. The panel organizers and panelists especially represent recently funded projects by the DOE ARPA-E SHARKS program and several DOE Water Power Technology Office initiatives.

SPEAKERS AND PRESENTATIONS:

> **Establishing the ARPA-E SHARKS Program**  
Mario Garcia-Sanz, Program Director, DOE ARPA-E

> **Sustainable, Predictable Renewable Hydrokinetic Energy for Off-Grid Communities**  
Alexandre Paris, President & CEO, ORPC Canada

> **Irony & Urgency: Environmental Review of Wave and Hydrokinetic Energy Projects**  
Paul T. Jacobson, Principal Technical Leader, Water and Ecosystems, EPRI

> **Direct Drive Wave Energy & Pulsed Power Conversion**  
Joseph H. Prudell, Director Oregon Corporate Operations, C·Power

> **Impact of Control Methodology on MHK Device Design**  
Alan McCall, Centipod Program Director, Ecomerit Technologies

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**Monday, October 11 12:30PM-2:00PM**

**SS25 | Power Electronics Enabled Power System with High Penetration of Renewables**

**SESSION ORGANIZERS:**

**Dr. Rui Yang,** Senior Research Engineer, National Renewable Energy Laboratory (NREL)

**Dr. Mahshid Amirabadi,** Assistant Professor, Northeastern University

The recent advancements in power electronics, solid-state technologies and artificial intelligence are reshaping the traditional view of power distribution systems. The number of power inverters and converters increases significantly due to the high penetration of renewable energy sources and energy storage devices. While much progress has been made in advancing power grids and power electronics technologies, less attention has been paid to bridging the gap between these two traditionally disjoint areas. This session will cover a broad range of contents in the area of power electronics enabled power systems, to address topics such as the impacts of high penetration of renewables and power converters to the power grid and electricity market.

**SPEAKERS AND PRESENTATIONS:**

> **Transportation Electrification and Its Grid Impacts**  
Xi (Lucy) Lu, Ford Motor Company

> **Impacts of High Penetration Renewables on Voltage and Frequency Stability**  
Yizhe Xu, Grid-Bridge

> **The Application of Siemens SCUC Engine On Various Electricity Markets**  
Ting Dai, Siemens

> **On Board Charger: Transforming EV/HEV into Distributed Energy Resources**  
Zhe Zhang, Eaton
If only: designing smaller, faster chargers was easier...

The world’s first MasterGaN 600V half-bridge driver with two integrated GaN power transistors

ACCELERATE THE CREATION OF NEXT-GENERATION COMPACT AND EFFICIENT CHARGERS AND POWER ADAPTERS

Advantages of our MasterGaN platform embedding a half-bridge driver based on silicon technology along with a pair of gallium-nitride (GaN) transistor

- **Higher efficiency**: reduced power losses and power consumption that exceed the most stringent energy requirements
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- **Faster time-to-market**: packaged solution simplifies the design and ensures a higher level of performance
- **More robust**: offline driver optimized for GaN HEMT for fast, effective and safe driving and layout simplification

Board area and weight are becoming limiting factors as power demands increase. Reducing size and weight can cut the total cost of ownership by making installation and maintenance both easier and quicker.

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<th>Key features</th>
<th>Output Current max (A)</th>
<th>High side $R_{DS(on)}$ (mΩ)</th>
<th>Low Side $R_{DS(on)}$ (mΩ)</th>
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EVALMASTERGAN

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Photovoltaic (PV) is one of the renewable favorites with a fast-growing rate, and much more are expected in the future. However, the massive installation of grid-connected PV systems creates many challenges to the grid. Many attempts have thus been made and being explored to better integrate PV systems as grid-friendly systems, which not only minimize the impact on the grid but also offer smart controllability and flexible manageability to enhance the grid performance. To master and then further advance the PV technology, we should understand the basics of PV systems like how the power conversion works, what the technological bottlenecks are, and what is the potential impact for largescale adoption of power electronic-based PV systems? And, how do we address the increasing issues outlined, e.g., by grid codes and standards, IEEE Std. 1547-2018, through advanced control strategies? The tutorial is proposed, and it is dedicated to tackling the technological challenges of nondeterministic power generation in grid-connected PV systems. It provides a step-by-step design of grid-friendly PV systems including the PV modules and power converters, and then a comprehensive understanding of the basics of PV systems. The focus is to innovate and improve the operability by means of advanced control to create more sustainable, grid-friendly, and reliable PV systems that comply with grid regulations and contribute to reducing the cost of energy. This enables the grid-supportive operation of PV systems, e.g., inertia emulation, to improve the grid performance. The tutorial is intended for intermediate and advanced audiences in the field of power electronics, engineers, and researchers, who are looking for advanced control solutions to power converters, especially focused on PV conversion systems for distributed generation. Researchers and engineers who seek for the basic knowledge for the PV technology are welcomed.

This tutorial focuses on studying of electromagnetic interference (EMI) reduction oriented advanced pulse-widthmodulation (PWM) technologies. EMI is a serious threat to the reliability and operation of the power electronics converters as motor drives. PWM is one of the most important factor for EMI in power electronics converters. Advanced PWM methods can be developed with freedom to optimize EMI and other parameters. In this tutorial, series work of advanced PWM which used freedom to optimize performance will be presented. The tutorial begins with the introduction of EMI problems and PWM technologies in power electronics converters. Then, PWM’s impact on the converter performance is discussed for power losses, current ripple and EMI. With current ripple as the control target, the prediction model is studied as the basis for PWM. On the basis of the prediction model, variable switching frequency PWM (VSFPWM) is proposed. This method can improve the EMI and power losses together with control of current ripple or other related parameters. For the general issues of VSFPWM, including the impact on harmonics and feedback control will also be illustrated. For common-mode (CM) EMI issue, this tutorial is with special care. PWM can help to reduce the CM voltage of regular two-level converter, but cannot eliminate it theoretically. For three-level converter, zero CM PWM is possible but with many penalties. A novel zero-CM PWM method for paralleled converters is introduced, together with its further improving methods. This method can be integrated with electric machine and further improve the power density. This tutorial is based on the series work of the presenters’ group as well as researchers all over the world. The major contents are included in the newly published book “Advanced Pulse-Width-Modulation: with Freedom to Optimize Power Electronics Converters” by Springer Press.
Tutorials

9AM3 | A MATLAB/Simulink Approach of Photovoltaic Power Systems: Designing, Modeling, Simulation, and Control

INSTRUCTORS: Weidong Xiao¹, Jimmy Chih-Hsien Peng², Qiang Han³
¹University of Sydney, Australia; ²National University of Singapore; ³BC Hydro, Canada

This tutorial provides a practical introduction to photovoltaic (PV) power systems regarding the theoretical analysis, design, modelling, control, and simulation. The objective is to expose the audience to all facets of PV power systems with emphasis on the hands-on tools required for executing academic research and for meeting industry expectations. The development of this tutorial is based on the diverse experience and expertise of the presentation team in both the academia and power industry. The tutorial will first begin with the fundamentals of PV systems regarding theoretical analysis and design. The modelling includes two parts; one for simulation, and another for dynamic analysis. Based on the system dynamics, a control design approach for grid-forming inverters is introduced to guarantee the system stability and robustness in the presence of multiple PV systems. Finally, transient studies for transmission-level connected PV systems are presented. All analysis and simulation are conducted using function blocks in MATLAB\Simulink environment. After the tutorial, the audience shall be able to design a practical grid-tied PV power system, simulate its operation, and evaluate its performance via MATLAB\Simulink. The tutorial will be organized to facilitate smooth transitions from the fundamental and practical knowledge to more advanced subjects.

10AM1 | Emerging Bidirectional Switches and Their Impact on Future AC Power Converters and Applications

INSTRUCTORS: Thomas M. Jahns¹, Bulent Sarlioglu¹, Johann W. Kolar², Jonas Huber², Victor Veliadis³
¹University of Wisconsin - Madison, United States; ²ETH Zurich, Switzerland; ³PowerAmerica, United States

This tutorial will introduce participants to the emerging technology of monolithic bidirectional (M-BD) power switches and the exciting opportunities they will open for future ac power converter topologies and their applications. Wide-bandgap (WBG) power semiconductor technology has opened the door to the development of long-sought monolithic bidirectional switches that can block voltage and conduct current in both polarities under full gate control in all four quadrants. Prototype versions of these M-BD devices produced in industrial and academic laboratories have been reported with ratings as high as ±1400V and ±100A. A section of this tutorial will be devoted to exposing participants to the underlying semiconductor technology of these M-BD switches including their operating principles, achievable terminal characteristics, technical challenges, and promising M-BD devices reported to date. Following this introduction to state-of-the-art M-BD switch technology, the tutorial will focus attention on the strong potential this new class of switches holds for having a major disruptive impact on the future of power electronics. In particular, this tutorial will focus on the exciting opportunities that these new switches provide for dramatically improving key performance metrics of future dc-ac and ac-ac power converters, including their power density, efficiency, EMI suppression, and (eventually) cost. Two of the well-known power converter classes that will be among the biggest beneficiaries of the future availability of M-BD switches are matrix converters (MCs) and current-source inverters (CSIs). While the appealing advantages of matrix converters for direct ac-ac power conversion have long been recognized, the unavailability of M-BD devices has prevented MCs using the baseline 3x3 matrix of ac switches from achieving wide commercial success. After reviewing the basic concepts associated with matrix converters and their control, attention will be focused on the opportunities that M-BD switches open for realizing the full commercial potential of future MCs in applications such as motor drives. Similarly, the future potential of new M-BD switches to revive long-neglected CSI technology will also be explored. Recent work has revealed a variety of appealing properties of CSI-based motor drives in a wide variety of dimensions including high-temperature operation, EMI suppression, and enhanced fault protection in permanent magnet machine drives. After reviewing the basic concepts of CSI technology for both ac-dc and dc-ac power converters, special attention will be focused on the game-changing potential of M-BD switches in future CSI-based integrated motor drives that combine motors and drives into the same housing. Finally, opportunities to realize the full potential of M-BD switches in promising new power converter topologies...
will be explored. One particularly exciting development is their application in a new T-Type switching cell (TT-SC) topology that provides the basis for designing high-performance WBG-based threelvel voltage-source inverters that can achieve appealingly high power density and efficiency performance metrics. Other promising power converter applications of M-BD switches will also be reviewed. Tutorial participants can expect to leave this tutorial with valuable insights into the emerging technology of M-BD switches and the opportunities they open for more fully exploiting wide-bandgap switch technology to revolutionize the power electronics field.

**10AM2 | Interaction Among the Grid-connected Converters through Their Synchronization Mechanism**

INSTRUCTORS: Marco Liserre¹, Grahame Holmes², Mario Paolone³, Rongwu Zhu⁴, Roberto Rosso⁵

¹Christian-Albrechts-Universität zu Kiel, Germany; ²RMIT University, Australia; ³Swiss Federal Institute of Technology, Switzerland; ⁴Harbin Institute of Technology, Shenzhen, China; ⁵ENERCON, Germany

Electrical power systems are currently transitioning from centralized structures, where most of the power generation comes from small numbers of large power rotating machines, to distributed structures, where much of the power generation comes from large numbers of small power-electronic-interfaced renewable resources. This increasing use of multi-functional power electronic converters (such as STATCOM, DVR, UPFC, UPS and Solid-state Transformer) is challenging the principles of electrical grid operation. One emerging area of concern is harmonic stability issues created by large numbers of grid-connected power converters, with converter synchronization to the grid emerging as a critical factor which can cause anomalous interactions between these converters. This tutorial considers this synchronization issue from the perspective of both the electrical power grid and the converter. The tutorial begins with the electrical grid perspective, looking at limitations of conventional grid modelling approaches in the presence of gridconnected converters, and then presenting advances that have been made in this area. Next, the tutorial reviews grid-synchronization from the converter perspective, looking at modelling issues, established grid synchronization strategies and grid converter classification implications. The tutorial then presents power synchronization as an emerging alternative for Grid-Forming-Converters, and considers its benefits in comparison to a Phase-Locked-Loop approach. Finally, the tutorial presents the idea of selfsynchronization, where the converter synchronizes to internal control loop variables instead of measured voltages, to improve its stability and ride-through capability in the presence of grid harmonics and faults.

**10AM3 | Wide Bandgap Power Electronics Based Electric Machine Drives**

INSTRUCTORS: Jin Wang¹, Yousef Abdullah²

¹The Ohio State University, United States; ²Kuwait University

The demand on high performance high power density electric machine drive systems continues to grow as multiple industry sectors look to cut costs and improve power density and efficiency. For this reason, researchers and engineers have been working on wide bandgap (WBG) based power electronics circuits to meet the immediate needs of industry and satisfy future requirements. The following tutorial provides an in-depth look of challenges and status or WBG motor drives, covering topics on both circuit level and system level, which includes gate drive design, circuit layout, reflective wave, thermal design, EMI, leakage current, and insulation stress to motor windings with high dv/dt PWM. Two case studies, one on a 1.8 kVA integrated GaN based motor drive and the other on 7 kV 1 MVA SiC based motor drive, will be used as examples during the discussion.
**10AM4 | Monitoring Power Module Degradation via Lifetime-Varying Parameters**

**INSTRUCTORS:** Christoph H. van der Broeck\(^1\), Timothy A. Polom\(^2\)

\(^1\)FEV Europe GmbH, Germany; \(^2\)Silicon Austria Labs GmbH, Austria

This tutorial introduces and breaks down thermal response monitoring and degradation diagnosis techniques especially applicable to power electronic modules. Such monitoring technologies are essential in next-generation integrated power electronic systems that require reduced size, weight and cost while ensuring highly reliable operation over ever extending lifetimes. The introduced methodology ultimately enables realization of predictive maintenance strategies that utilize power converters fully until critical degradation thresholds are reached. They allow operating lifetimes of power conversion systems to be maximized or optimized according to engineering and availability constraints. Degradation mechanisms in power electronic modules occur at material interfaces in large part due to mismatches in thermal expansion coefficients. Resulting thermal cycles periodically induce strain at these material interfaces which, in turn, leads to fatigue, i.e., crack growth and delamination. In many cases, the growth of cracks and delamination occurs within the primary heat dissipation path of a power device, thus altering thermal response. The presented scheme of detection, localization, and overall quantification of different degradation mechanisms is based on systematically monitoring lifetime-varying electrothermal response properties and parameters. This tutorial has the objective to present and clarify details of the many promising research approaches that have been recently proposed to realize in situ health monitoring and diagnosis. After establishing motivation, this tutorial reviews electrothermal modeling approaches especially applicable to power modules and examines typical electrothermal response characteristics. Moving forward, it details thermal real-time monitoring systems that combine temperature data, extracted via sensors and temperature-sensitive electrical/optical parameters, with 3-D real-time models. It is demonstrated how the fusion of model and sensor data can detect abnormal thermal responses, which are linked to occurrences of degradation. Page 2 of 3 The tutorial provides an overview on thermal characterization technologies that measure thermal impedance in time and frequency domain. It is analyzed how thermal impedance reflects different degradation mechanisms and can serve as the focal point of a scheme to localize and quantify these mechanisms. Addressing the broad array of implementation options, the final part of the tutorial investigates real-time technologies that can extract life-time varying thermal parameters, in particular thermal impedance, during normal converter operation. It finally shows how extracted degradation sensitive data can be utilized for degradation diagnosis using artificial intelligence technologies.

**11AM1 | Advances in Intelligent Solid-State DC Substations for Future Interconnected DC Grids**

**INSTRUCTORS:** Rik W. De Doncker, Jingxin Hu, Shenghui Cui, Johannes Voss, Philipp Joebges

RWTH Aachen University, Aachen, Germany

The change of the electrical supply system to more environmental-friendly energy sources require the development of a new grid infrastructure. Next to the increasing penetration of large-scale renewable energy sources such as offshore wind farms, the change of consumer behavior in the distribution grids from consumer into producer due to the installation of decentralized generations will result in a bottleneck in the distribution grids. Local or regional balancing between loads and generations is found to be a cost effective solution for the future electrical distribution grids, which can be realized with direct current (DC) technology more efficiently and flexibly. The tutorial will focus on the latest advances and best practices of intelligent solid-state DC substations for future flexible DC grids, which covers a selection of key enabling technologies from converter topologies, optimized control, hardware-in-the-loop simulation techniques, to the development of megawatt mediumvoltage demonstrators. The presented advances are collected from a number of recent and ongoing research projects in the Institute for Power Generation and Storage Systems, which includes the Flexible Electrical Networks (FEN) Research Campus funded by the German Federal Ministry of Education and Research. Following a general introduction and a technology roadmap of flexible DC grids, the tutorial will elaborate the technologies of bidirectional isolated DC-DC converters for intelligent solid-state DC substations for...
interconnection of DC grids at different voltage levels. It will start with dual-active bridge (DAB) based DC-DC converter topologies for LVDC-MVDC applications, where advanced modulation and control of DAB converters will also be discussed. This includes the instantaneous flux and current control method as well as the advanced black start-up and fault ride-through strategies for a highly dynamic and robust operation under both normal and fault conditions. Then, the development and control of an IGCT-based 5 kV, 5 MW DAB DC-DC converter will be presented. This includes the employment of the modified auxiliary-resonant commutated-pole circuit to ensure zero-voltage soft-switching of IGCT devices with snubber capacitors, and a novel anti-saturation detection and compensation methods for medium-frequency transformers. Considering the numerous benefits of the bipolar DC distribution, the tutorial will also present advances in power conversion technologies for bipolar LVDC and MVDC distribution systems. The concept of topological integration is adopted and demonstrated for state-of-the-art AC-DC and DC-DC converters such as MMC and DAB, which enables a full bipolar operation capability on the DC side with a minimum count of additional components. The last section of the tutorial will deal with the real-time simulation and hardware-in-the-loop test for intelligent DC substations. Different modeling techniques will be discussed and compared with best practices in the real-time environment. A successful example of using the rapid-control-prototyping tool to develop a high-power medium-voltage modular DC-DC converter will be presented as well as the lessons learnt.

11AM3 | Optimised Electrical Machine Designs for E-Mobility Applications

INSTRUCTORS: Mircea Popescu¹, Philip Mellor², Nick Simpson², James Goss, Melanie Michon¹, Jonathan Godbehere¹

¹Motor Design Ltd., United Kingdom; ²University of Bristol, United Kingdom

Transport electrification is seen as one of main solutions to reduce global CO2 emissions and increased demand of mechanical energy can be provided by electrical energy. The best energy conversion systems are undoubtedly the combination: electrical machines + power electronics + batteries. The increasing demand of full electric vehicles arises specific challenges in terms of design for manufacturing, low weight, material costs and material supply chain. There is a strong interest to reduce the volume and cost of active materials in propulsion motor technologies beyond their current state-of-art, with a strong focus on industrial feasibility for mass production. Potential solutions include increased motor speeds and higher pole numbers and/or the adoption of rare earth free typologies such as reluctance (switched and synchronous) and induction machines. As there can be significantly different usage and performance requirements across e-mobility applications adopting a common standard of motor design is unlikely to yield the optimum in terms of overall system efficiency and electric vehicle range. These considerations will be discussed and compared. Advances in fast switching power semiconductor devices and digital control have enabled high frequency operation of electrical machine drives, with fundamental operating frequencies exceeding 1 kHz being proposed. High frequency operation allows for greater mechanical speeds and designs with a larger number of magnetic poles, leading to a more compact electrical machine package for a given output requirement. However, high frequency operation results in a higher volumetric loss in he active components of the electrical machine; primarily as a result of induced circulating eddy currents in the stator laminations, winding conductors and the rotor. The non-uniform heating and reduction in efficiency associated with these AC loss effects represent a major hurdle to the successful development of compact high frequency electrical machine drives. The benefits and challenges associated with high frequency operation of electrical machines for aerospace and automotive applications will be reviewed and the techniques and design choices available to the designer to reduce high frequency loss effects and extract heat will be surveyed. Cutting-edge sensitivity analysis and multi-objective optimisation techniques will be applied in the design of an electric motor for a PHEV traction application. Each candidate solution will be evaluated in terms of electromagnetic, thermal and mechanical behaviour across the full operating envelope. The optimisation will generate a pareto front which allows efficiency over a drive cycle to be traded off against motor cost. This approach utilises a high performance or cloud computing infrastructure to deliver a truly revolutionary design workflow.
11AM4 | Conducted, Near-Field and Radiated EMI Emission Mitigation for Wide Bandgap Converters: Fundamentals, Modeling and Solutions

INSTRUCTORS: Cong Li¹, Shuo Wang²
¹GE Research, United States; ²University of Florida, United States

This seminar is part of a series of education activities initiated by IEEE EMC Society Special Committee 5 (SC5) – Power Electronics EMC. The purposes are to raise broader power electronics audiences’ awareness of EMC, and connect advanced EMC technologies with WBG power electronics systems to enable low noise, high efficiency, and high power density solutions for future power conversion systems. This seminar is a comprehensive guide to provide engineers with techniques to develop and construct electromagnetically compatible Wide Bandgap (WBG) power electronic converters. The seminar provides a good opportunity for the fundamental theory, measurement, and suppression of electromagnetic interference (EMI) for WBG power electronics. It will have full coverage on the conducted emission, near field, and radiated EMI. The first section provides EMC theory and fundamentals for WBG power conversion, comparison of commonly used industrial EMI standards, techniques for common-mode (CM) and differential mode (DM) current separation, and practical CM/DM measurement methods. The second section focuses on a comprehensive 5-step EMC design process for WBG power converters’ conducted emission EMI challenges: “SOLVE”. SOLVE design flow begins with considerations on Selecting proper architectures based upon system ratings and EMC specifications. The next steps develop techniques for Obtaining component parasitics and Layout for the system EMI model. Vetting of different filter design aspects, including magnetic material selection, structure, and practical filter performance. The last step presents techniques and principles for packaging Enhancement. The third section focuses on the near field EMI generated from components in WBG power converters. The near field EMI can be generated from WBG power modules, transformers, inductors, and PCB traces. It can be coupled to other components in the converter to deteriorate the WBG converter’s conductive and radiated EMI. With the high switching speeds and high switching frequencies of WBG power electronics to improve power density, the components are very close to each other, therefore the importance of understanding, measurement, and reduction of near field EMI cannot be overemphasized. The seminar will focus on the advancement of the theory, identification, and reduction of the near field EMI for WBG power electronics. The fourth section focus on the radiated EMI for WBG power electronics. The WBG device powered power electronics systems can achieve higher power densities than those with the 2 conventional Si devices. However, higher switching speed and higher switching frequencies lead to more significant radiated EMI. The radiated EMI can be over the limits from several to hundreds of MHz, which poses a big barrier to high power density power electronics design in the areas such as consumer electronics, electric vehicles, and the aviation industry, etc. This is especially important for most power electronics engineers who lack knowledge on the radiated EMI in power electronics systems. The seminar will focus on the advancement of the theory, measurement, and reduction techniques developed in recent years for the radiated EMI in WBG power electronics systems.

12PM1 | Applying Artificial Intelligence to Battery State Estimation

INSTRUCTORS: Carlos Vidal¹, Phillip Kollmeyer¹, Javier Gazzarr²
¹McMaster University, Canada; ²MathWorks, United States

This tutorial will teach the entire process necessary to create, test, and deploy machine learning algorithms which estimate battery state of charge or other states and properties of interest. Traditional state estimation methods depend on battery models that cannot always capture the complex nonlinear, temperature-dependent characteristics inherent in battery electrochemistry. Machine learning simplifies the process by treating the battery as a black box. The relation between states of interest and measured battery parameters are fit to a neural network, which is a series of matrix calculations containing hundreds or thousands of learnable parameters. Machine learning has potential to achieve better accuracy than conventional battery modeling and state estimation techniques and is a promising solution for a wide range of commercial and industrial applications. Battery state estimation and machine learning theory will first be introduced, along with a discussion of different types of machine learning methods that can be
applied to battery applications. Then the steps to create a machine learning algorithm - an experimental collection of data, defining network configuration and hyperparameters, training, and testing - will each be discussed in detail. A case study comparing a non-recurrent feedforward neural network with a recurrent, LSTM-based neural network will be provided, demonstrating that both network types can perform very well for realistic vehicle drive cycles over a wide range of temperatures. The tutorial will also include an interactive session where the attendees will train and test neural networks for the state-of-charge estimation via example data and code executing in MATLAB Online, which can run in any web browser. Following the training and testing process, the next step is to deploy the networks in hardware and evaluate their real-time performance and computational load. The method of saving a neural network as a MATLAB object for direct use in Simulink, auto-generation of C-code, and deployment to a real-time target, such as a battery management system, will be demonstrated. Example results showing processor time as a function of algorithm type and several learnable parameters will be given. It will provide insights into machine learning algorithms' suitability for large battery packs with a hundred or more cells. The tutorial will also provide several other examples of how to apply machine learning to battery applications, including (1) use of machine learning in place of equivalent circuit models, (2) estimation of temperature to reduce the need for physical sensors in a battery pack, and (3) state of health estimation.

**12PM2 | Resiliency-Oriented Grid-Interactive Converters: Concepts, Design, and Field Implementation**

**INSTRUCTORS:** Xiaonan Lu¹, Jin Tan², Andy Hoke², Lisa Qi³

¹Temple University, United States; ²National Renewable Energy Laboratory, United States; ³ABB Inc., United States

As the penetration level of inverter-based distributed energy resources (DERs) increases rapidly, distribution grids, as the most significant ‘grid-edge’ for DER integration, play a crucial role in bridging the grid backbone (i.e., transmission system) to the end-users. Resilient and stable distribution grids are urgently needed to modernize electric power grids with high penetration of inverter-based resources (IBRs) and ensure operational continuity. Conventional grid-interactive power electronic converter design mainly focuses on satisfying the design constraints of individual converter units and the operational requirements at the single point of interconnection (POI). However, given the increasing penetration level of IBRs in modern power grids, converter systems should also be taken into account to meet the grid needs in a wider area. Furthermore, the concept of converter design has been tremendously advanced, considering the cross-domain and multi-disciplinary objectives. Particularly, on top of the conventional and legacy converter design constraints on power density, energy conversion efficiency, among others, additional considerations on the interactions among multiple converters (i.e., converter systems) should be highlighted, with special emphases on the coupling operation between converter hardware implementation (physical layer) and information exchange through communication interconnections (cyber layer), control design respecting the tradeoff between local control constraints satisfaction and interactive operation with neighboring converters, and fault-tolerant design and converter system resiliency enhancement coordinated with conventional protection schemes in a multi-timescale context. All these emerging design constraints call for a paradigm shift into a resiliency-oriented converter design framework. In this tutorial, the diversified and multi-disciplinary instructor team from academia, government national laboratories, and leading industry companies will introduce the resiliency-oriented modeling and control of grid-interactive converter, and the topics will range from fundamental concepts covering the necessary background knowledge to advanced applications and field deployment. The topics will echo the cutting-edge technologies and applications of grid-interactive converters, including hybrid and networked AC and DC microgrids, inverter-based renewable energy (e.g., photovoltaics) integration, resiliency enhancement, and protection coordination in inverter-dominated power grids, among others.
12PM3 | Cryogenic Power Electronics Design for Electrified Aircraft Propulsion

INSTRUCTORS: Fei (Fred) Wang¹, Zheyu Zhang², Ruirui Chen¹, Shengyi Liu³
¹University of Tennessee, United States; ²Clemson University, United States; ³Boeing Company, United States

Cryogenic power electronics offer numerous game-changing benefits, including 1) improved performance of power semiconductor devices, such as silicon (Si)- and gallium nitride (GaN)- based, offering decreased specific on-state resistance and increased switching speed; 2) faster switching frequency operation at cryogenic temperature, greatly reducing the need for passive (e.g. EMI filtering); thereby reducing filter weight; 3) less cooling requirement at extremely low ambient temperatures, and 4) light and/or efficient busbar designs due to the low resistivity of conductors at cryogenic temperature. This seminar will provide several key perspectives for the cryogenic power electronics design from the component up to the converter level. First, the characteristics of critical components, including power semiconductors and magnetics, at cryogenic temperature are introduced. Second, special considerations, trade, and design studies of cryogenic power stage and filter are discussed. Then, two examples of a 40 kW Si-based and a 1 MW SiC-based cryogenically-cooled inverter system for electric aircraft propulsion are illustrated, with cooling design, safety considerations, and the protection scheme highlighted. Upon completion, seminar attendees will have a firm grasp on the cryogenic power electronics design and be provided with a range of possible options in order to better utilize the cryogenic cooling system in power converters.

12PM4 | Hybrid Semiconductor Switches based Power Modules, Converters, and Systems

INSTRUCTORS: Fang Luo¹, Jiangbiao He²
¹State University of New York at Stony Brook, United States; ²University of Kentucky, United States

Power semiconductor devices play a backbone role in the development of power electronics. Over the past decade, semiconductor devices have experienced rapid development, especially promoted by the emerging wide-bandgap device technologies. However, regardless of conventional Silicon (Si) devices or the new Gallium Nitride (GaN) and Silicon Carbide (SiC) devices, every type of semiconductor devices has its own pros and cons. To fully leverage their different characteristics, various hybrid power devices and modules have been proposed and developed in the past years, ranging from the device level to converter level, or even power electronics system level. As a matter of fact, many of the concepts of hybrid semiconductor switches have been successfully applied in industries, such as the monolithic integration of Si IGBTs and SiC anti-parallel diodes (i.e., co-pack), the Cascode JFET, and the “Si+SiC” hybrid three-level active neutral-point-clamped commercial modules. Numerous performance benefits have been achieved with such hybrid devices, modules, and converters, including efficiency and reliability improvement, EMI mitigation, cost reduction, etc. In this tutorial, we will start with a review of the development history of various hybrid semiconductor devices and the related successful commercial examples, followed by the new opportunities and challenges with the emerging wide bandgap devices. Afterwards, we will present “Si+SiC” hybrid switching devices at the power module level, review the operating principle, gate drivers, packaging, and performance evaluation. Furthermore, we will present various “Si+SiC” hybrid power converters, specifically including the hardware development, controls, and experimental verifications. Application examples include electric aircraft propulsions and interruptible power supplies for data center applications will be discussed. Finally, we will conclude the tutorial with a summary and Q&A session.
Design and Development of Scalable Battery Testers/Emulators and Their Applications for Future Transportation Electrification

INSTRUCTORS: Sheldon Williamson¹, Uday Deshpande²
¹Ontario Tech University, Canada; ²D&V Electronics Ltd., Canada

As electrified transport systems proliferate, batteries are increasingly becoming the critical element in the immediate and long-term technical and commercial success of these programs. Understanding of battery technology and its role in the applications is becoming crucial. While there have been many articles published on battery elements and systems, this tutorial approaches the problem from a user mindset. How do we use the various technology elements of battery models, calculations of charge and health to ensure a successful design outcome? Additionally, this tutorial will discuss how these elements apply to test and validation. Very few battery cell models are available in literature; most models are very generic or basic. Cell models are either based on equivalent circuit parameters, such as RC, R-RC, or based on SOC calculation - these are not enough to measure Ah-capacity fade, state-of-health (SOH), and/or end-of-life (EOL). Thermal modeling is used minimally in related literature for testers and emulators. Cell degradation assessment due to varying temperature gradients is not feasible - this is particularly true for fast charging applications; 1C and above. Hence, testers/emulators today are unable to provide boundary testing (near EOL), specifically for applications such as fast chargers and controller validation or BMS validation. This tutorial will present more realistic and practical electro-chemical and electro-thermal models for emulation and testing purposes. Performance modeling will be presented in order to test advanced machine learning (ML)-based battery management systems (BMS) and charger controllers. Stochastic models of battery cells will also be presented in this tutorial. In addition, SOC/SOH estimation models specific to emulator/tester applications, which affect instantaneous battery performance, will also be presented. Advanced thermal/EOL degradation models, which can be used to test BMS with battery health estimation and energy management, will also be presented for testing applications. Finally, the tutorial will include emulation of custom cell models and health-conscious fast charging algorithms, keeping the effects of temperature gradients in mind. Keeping these aspects in mind, the following key practical aspects will be presented: • Emulation at cell-level, module level, and pack level (including development of advanced, higher order thermal models); • Estimation of SOC and SOH using advanced ML techniques; • Validation of BMS developmental steps with respect to hardware, firmware, and software; • Testing of newly developed algorithms (balancing, SOC, SOH, EOL, etc.); • Development of a new constant-temperature-constant voltage (CT-CV) algorithm; • Testing of fault cases (over-temperature, over-voltage, etc.); • Programmable standard and user-owned battery models; • Bidirectional power supply design (regenerative design) for high-power discharge; Constant-Voltage (CV), Current (CC), Power (CP), Series Resistance (CR) loading; • Real-time HIL (Simulation of high-voltage batteries at cell/module level; Real-time multi-cell battery simulations; Temperature simulations using isolated analog outputs and advanced models).

Printed Circuit Boards in Power Converter Applications: Design Considerations and Failure Mechanisms

INSTRUCTORS: Ashish Arora, Yike Hu
Exponent, United States

Printed Circuit Boards (PCBs) are the backbone of all electronic circuits and are ubiquitous in today’s world in almost all applications. PCBs not only interconnect components through conductors routed through the board with traces and vias, but also provide electrical insulation between conductors of different potentials that are in different circuit nodes. Their use in power converter and energy storage applications gives rise to risks that do not necessarily exist in other lower power applications. While PCB failures are not very common, a propagating PCB failure in a power converter or energy storage application can trigger a cascading series of failures that spread to the system’s energy storage component eventually resulting in a fire. Propagating PCB failures can occur due to a number of reasons such as contamination on the PCB, improper PCB layout or a failure of a component on the PCB itself. Design choices made during the development of a product, the cleanliness of the PCB manufacturing
process, the stresses applied to the PCB during a products assembly process etc. can all impact the probability of a PCB failure in the field. Understanding the causes of PCB failures and how these failures can propagate in an application allows for the design and manufacture of systems with more robust PCBs that have a lower probability of a catastrophic failure in the field. This tutorial will provide an overview of some of the requirements and challenges of designing and manufacturing PCBs specially for power converter and energy storage applications. The tutorial will also provide an overview of the types of PCBs, how PCBs are manufactured, how components get onto the PCBs and the standards that exist to evaluate the PCB manufacturing process. PCB failure mechanisms such as interconnect overheating, contamination, electrochemical migration, dendrite formation and conductive anodic filaments, tin whiskers and component over-heating will be reviewed. Case studies will provide examples of failures observed in the field and the means to mitigate them.

1PM3 | Defining, Modeling, and Optimizing for Energy Efficiency in 5G

INSTRUCTOR: Brian Zahnstecher
PowerRox, United States

With so much hype and news around the deployment of the next-generation broadband network (5G), it is quite alarming to find out much of the “promise” of 5G assumes the energy infrastructure exists to power all this new HW. More fundamentally, the payback estimates for these massive investments all assume the network can be fully utilized, while neglecting network bottlenecks because they relate to energy and not data throughput. The 5G Energy Gap and potential electrical grid destabilization is a risk to the entire deployment and all that is attached to it. This risk is broken down into the concepts of the Power Value Chain, Power Cost Factor, 5G Derate Factor, and other technical/business and even socioeconomic factors. This entry/intermediate-level seminar introduces these concepts in a simple, yet realistic way to break the complicated network down into manageable pieces for all stakeholders, then translate the unique inputs/requirements of each into the normalized, “universal currency” of energy. From there, both static and dynamic analyses can be performed to assess end-to-end network configurations and optimize each piece through the lens of energy efficiency.
Technical Program

The following Sessions cover all areas of technical interest to the practicing energy conversion professional.

Ask the authors questions using the Chat located next to each pre-recorded video.

Topic A: Renewable and Sustainable Energy Applications

A01: Photovoltaic Systems

1772 | Comparison of Modulation Techniques for a Single-Phase Full-Bridge Photovoltaic Micro-Inverter considering Reactive Power Capability
Tobias Brinker, Lennart Hoffmann, Jens Friebe
Leibniz Universität Hannover, Germany

1294 | Experimental Analysis of Laminated Bus Bars for Building-Integrated Photovoltaic Applications
S. Ravyts1, P. Nivelle2, J. Carlous2, R. Sabariego3, M. Daenen2, J. Driesen3, J. Cappelle1
1KU Leuven - Gent, Belgium; 2Hasselt University, Belgium; 3KU Leuven - Leuven, Belgium

1779 | Influence of DC/DC Stage on the Design of the Output Filter of the Inverter Stage in Two-Stage Grid-Connected PV Systems
Branislav Stevanović1, Santiago Cóbreces2, Emanuel Serban3, Pedro Alou1, Martin Ordonez2, Miroslav Vasić1
1Universidad Politécnica de Madrid, Spain; 2Universidad de Alcalá, Spain; 3The University of British Columbia, Canada

1362 | Sizing Approach for a Single-Phase Grid-Connected Photovoltaic Converter with Active and Reactive Power Management
Rosa Iris Viera-Díaz, Mario González-García, Ricardo Álvarez-Salas, Homero Miranda, Yuniel León-Ruiz
Universidad Autónoma de San Luis Potosí, Mexico

A02: Renewable and Sustainable Energy Systems

2422 | Economic Analysis for Hourly Dispatching Wind Energy Power Using Battery and Supercapacitor Hybrid Energy Storage System
Pranoy Roy, JiangBiao He
University of Kentucky, United States

1819 | A Single-Phase Enhanced Grid-Forming Controller with Converter Current Limiting
Masoud Karimi-Ghartemani1, Ali Zakerian1, Sayed Ali Khajehoddin2
1Mississippi State University, United States; 2University of Alberta, Canada

1226 | Comparative Study of Transverse Flux Permanent Magnet Machines for Wind Power Applications
R. Kumar1, Z.Q. Zhu1, A. Duke2, A. Thomas2, R. Clark2, Z. Azar2
1The University of Sheffield, United Kingdom; 2Sheffield Siemens Gamesa Renewable Energy Research Centre, United Kingdom

2346 | Review of DC Offshore Wind Farm Topologies
Kareem A. Noor Al-Deen, Hussain A. Hussain
Kuwait University, Kuwait

1990 | Control Strategies for Variable Speed Operation of Pumped Storage Plants with Full-Size Converter Fed Synchronous Machines
Raghbendra Tiwari1, Roy Nilsen1, Olve Mo2
1Norwegian University of Science and Technology, Norway; 2SINTEF Energy Research, Norway
### A03: Power Converters for Renewable and Sustainable Energy Systems

<table>
<thead>
<tr>
<th>Session Number</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1328</td>
<td>Flexible AC Phase Configurable NPC-Based Converter Topology</td>
<td>Emanuel Serban(^1,(^2), Jan Hammer(^1), Cosmin Pondiche(^3), Martin Ordonez(^1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^1)The University of British Columbia, Canada; (^2)EnerSys, Canada</td>
</tr>
<tr>
<td>2144</td>
<td>Harmonics Compensation of the LCC in a Parallel LCC-VSCs Configuration for a Hybrid AC/DC Network</td>
<td>Rouzbeh Reza Ahrabi, Yunwei Li</td>
</tr>
<tr>
<td></td>
<td></td>
<td>University of Alberta, Canada</td>
</tr>
<tr>
<td>1192</td>
<td>A Dual-Input Single-Output DC-DC Converter Topology for Renewable Energy Applications</td>
<td>Pasan Gunawardena, Nie Hou, Dulika Nayanasiri, Yunwei Li</td>
</tr>
<tr>
<td></td>
<td></td>
<td>University of Alberta, Canada</td>
</tr>
<tr>
<td>2016</td>
<td>PWM Control of n-Phase Interleaved Current Fed Topology</td>
<td>Sonam Acharya(^1), Santanu Mishra(^1), Arvind Tiwari(^2)</td>
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<td></td>
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<td>(^1)Indian Institute of Technology Kanpur, India; (^2)GE Research, United States</td>
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### A04: Control of Photovoltaic Systems

<table>
<thead>
<tr>
<th>Session Number</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1563</td>
<td>Analysis of Maximum Power Point Tracking in Four Different Modes for Multioutput Hybrid Bipolar Converter</td>
<td>Nidhi Malhotra, Pawan Kumar, R.K. Singh</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Indian Institute of Technology (BHU), Varanasi, India</td>
</tr>
<tr>
<td>1904</td>
<td>Discontinuous Modulation for Improved Thermal Balance of Three-Level 1500-V Photovoltaic Inverters under Low-Voltage Ride-Through</td>
<td>Jinkui He(^1), Ariya Sangwongwanich(^1), Yongheng Yang(^2), Zhongyi Quan(^3), Yunwei Li(^1), Francesco Iannuzzo(^1)</td>
</tr>
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<td>(^1)Aalborg University, Denmark; (^2)Zhejiang University, China; (^3)University of Alberta, Canada</td>
</tr>
<tr>
<td>1482</td>
<td>A Semi Discontinuous PWM Method for Mitigating Oscillation in a Three-Level Grid-Tied PV Inverter</td>
<td>Zhaoxia Yang(^1), Jianwu Zeng(^1), Qixing Ren(^2), Liangcai Wu(^2), Zhengjun Liao(^2)</td>
</tr>
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<td></td>
<td></td>
<td>(^1)Minnesota State University, United States; (^2)Growatt New Energy Technology Co., Ltd., China</td>
</tr>
<tr>
<td>1864</td>
<td>Hybrid MPPT Technique Based on MPC and PSO for PV Systems Subject to Partial Shading</td>
<td>Angelo G. Santos, Filipe A.C. Bahia, Fabiano F. Costa, André P.N. Tahim, Leandro L.O. Carralero</td>
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<td>Federal University of Bahia, Brazil</td>
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<tr>
<td>1502</td>
<td>A Reactive Power Control Optimization Scheme for the Power Imbalance of Cascaded Photovoltaic Converter</td>
<td>Chu Wang, Min Chen, Yufei Jie</td>
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<tr>
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<td>Zhejiang University, China</td>
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<tr>
<td>1690</td>
<td>An Improved PV to Isolated Port Differential Power Processing Architecture for Solar PV Applications</td>
<td>Aqsa Rouf, Soumya Shubhra Nag</td>
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<tr>
<td></td>
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<td>Indian Institute of Technology Delhi, India</td>
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<tr>
<td>1389</td>
<td>A Decentralized Adaptive Voltage Regulation Control Strategy Based on a Novel Modular Three-Phase Integrated PV Inverter</td>
<td>Xinghua Dang, Shanzhi Pan, Xicai Pan, Jinwu Gong, Xiaolu Ge, Jingxiang Shi, Minglong Wang, Lidong Hao, Pengxin Jin</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wuhan University, China</td>
</tr>
</tbody>
</table>
Session A05: Energy Storage Systems

2053 | **Cell Balancing of Li-Ion Battery Pack with Adaptive Generalised Extended State Observers for Electric Vehicle Applications**  
Utkal Ranjan Muduli¹, Khaled Al Jaafari¹, Khalifa Al Hosani¹, Ranjan Kumar Behera²,  
Rustem R. Khusnutdinov³, Alfred R. Safin³  
¹Khalifa University, United Arab Emirates; ²Indian Institute of Technology Patna, India; ³Kazan State Power Engineering University, Russia

1666 | **Passivity Control in Modular Battery Energy Storage Systems**  
Ezequiel Rodriguez¹, Ramon Leyva², Gaowen Liang¹, Glen G. Farivar³, Josep Pou¹,  
Christopher D. Townsend⁴, Naga Braharendra Yadav Gorla¹  
¹Nanyang Technological University, Singapore; ²Universitat Rovira i Virgili, Spain; ³University of Western Australia, Australia

1299 | **A Comparison of the Battery Fault Tolerance of Modular Multilevel Converters with Half-Bridge and Full-Bridge Submodules**  
Gaowen Liang¹, Glen G. Farivar¹, Gorla Naga Braharendra Yadav¹, Christopher D. Townsend²,  
Salvador Ceballos¹, Hossein Dehghani Tafti¹, Josep Pou¹  
¹Nanyang Technological University, Singapore; ²University of Western Australia, Australia; ³Ikerlan Technology Research Centre (BRTA), Spain

1565 | **Design, Control and Prototyping of a Bidirectional Dual Active Bridge Converter for Integrating a Sodium Metal Halide Battery into a Telecom Station**  
Mario Porru¹², Alessandro Serpi¹², Alessandro Soldati¹, Luca Tassi³, Alfonso Damiano²  
¹NEPSY srl, Italy; ²University of Cagliari, Italy; ³University of Parma, Italy

1794 | **Design of a 1500V Si IGBT/SiC MOSFET Hybrid Switch-Based Three-Level Active NPC Inverter**  
Haichen Liu, Tiefu Zhao, Jim Gafford, Somasundaram Essakiappan, Madhav Manjrekar  
University of North Carolina Charlotte, United States

1894 | **A Novel ZCS Bidirectional CUK Equalizer for Energy Balance of Battery Cells Connected in Series**  
Xinchi He¹, Rui Ling¹, Dongxue Li²  
¹Chongqing University, China; ²Vicor Corporation, United States

1604 | **Novel Battery Equalizer-Charger Symbiosis Structure Based on Three-Port DC-DC Converters**  
Nguyen-Anh Nguyen, Phuong-Ha La, Ngoc-Thao Pham, Sung-Jin Choi  
University of Ulsan, Korea

1089 | **Solar Water Pumping System with Captive Energy Storage Functionality**  
Hina Parveen, Utkarsh Sharma, Bhim Singh  
Indian Institute of Technology Delhi, India

Session A06: Microgrids and Grid Integration of Renewables

1373 | **Mode Transition in DC Microgrids with Non-Dispatchable Sources**  
S. Jaya, A.S. Vijay, Imran Khan, Anshuman Shukla, Suryanarayana Doolla  
Indian Institute of Technology Bombay, India

2215 | **Subsynchronous Control Interaction Study Framework and Applications to Southern California Edison System**  
Chaoyang Jing, Patricia Arons  
Southern California Edison, United States
Technical Program

1550 | A Simulation Platform for Testing the Monitoring Techniques of a Microgrid
Mohd Aquib, Suryanarayana Doolla, Mukul C. Chandorkar
Indian Institute of Technology Bombay, India

2248 | Design and Optimization Strategy to Size Resilient Stand-Alone Hybrid Microgrids in Various Climatic Conditions
Norma Anglani¹, Giovanna Oriti², Ruth Fish³, Douglas L. Van Bossuyt²
¹University of Pavia, Italy; ²Naval Postgraduate School, United States

1807 | Dual Converter Operating with Floating Capacitors Connecting Open-End Winding Doubly-Fed Induction Generator to a DC Microgrid
Emerson L. Soares¹, Cursino B. Jacobina¹, Nady Rocha³, Victor Felipe M.B. Melo²
¹Federal University of Campina Grande, Brazil; ²Federal University of Paraíba, Brazil

1246 | A New General Multi-Layout Energy Hub Management Model for Industrial and Commercial Multi-Energy Systems with Complex Configurations
Mehrdad Aghamohamadi¹, Clement Chuah¹, Amin Mahmoudi¹, John K. Ward², Mohammed H. Haque³
¹Flinders University, Australia; ²CSIRO, Australia; ³University of South Australia, Australia

1859 | Sizing of Hybrid Supercapacitors for Off-Grid PV Applications
Tarek Ibrahim¹, Tamas Kerekes¹, Dezso Sera², Sergiu Spatharu³, Daniel-Ioan Stroe⁴
¹Aalborg University, Denmark; ²Queensland University of Technology, Australia; ³Technical University of Denmark, Denmark

1841 | Dynamic Analysis of AC Microgrids with Constant Power Loads or Sources
Mohammad Mahdavyfakhr,Navid Amiri, Hanqing Lin, Juri Jatskevich
The University of British Columbia, Canada

Session A07: Power Electronics for Renewable Energy Systems

2307 | Soft Switched High Gain Boost Converter for Low Voltage Applications
Manikant Kumar, Kirti Mathuria, Vinod Kumar Yadav, Arun Kumar Verma
Malaviya National Institute of Technology Jaipur, India

2132 | A Fully Symmetrical Three-Port Hybrid Converter for PV Systems
Zhongting Tang¹, Yongheng Yang¹, Freda Blaabjerg¹
¹Aalborg University, Denmark; ²Zhejiang University, China

1098 | Experimental Verification of Three-Phase PV Inverter Using Multiple Bidirectional Choppers for Utility-Scale PV Systems
Linyue Qiao, Yoshifumi Shimizu, Makoto Hagiwara
Tokyo Institute of Technology, Japan

2471 | Optimal Design of Multi-Port DC/DC Converters for Low Power and High Frequency Applications
Marzieh Karami¹, Guangqi Zhu¹, Rohit Baranwal¹, Vijay Bhavaraju¹, David W. Ganger¹, Cheng Luo²
¹Eaton, United States; ²Eaton, China

2567 | Design and Testing of a Modular Back-to-Back Power Electronics Converter for Wave Energy Harvesting
Mattia Mantellini¹, Riccardo Morici¹, Marcos Blanco², Marcos Lafoz³, Gustavo Navarro³, Luca Zarri³
¹OCEM Power Electronics, Italy; ²CIEMAT, Spain; ³University of Bologna, Italy

2447 | Design Considerations of 6.5kV Enabled Three-Level and 10kV Enabled Two-Level Medium Voltage SST
Apoorv Agarwal, Anup Anurag, Nithin Kolli, Ashish Kumar, Subhashish Bhattacharya
North Carolina State University, United States
1060 | Investigation of a New Alternate Arm Modular Multilevel Converter Topology for HVDC Applications
Dereje Woldegiorgis, Alan Mantooth
University of Arkansas, United States

1980 | A Hybrid GaN + Si Based Cascaded H-Bridge Multi-Level Inverter and PWM Scheme for Improved Efficiency
Prince Kumar1, D. Venkatramanan1, Abhijit Kshirsagar2, Ned Mohan1
1University of Minnesota Twin Cities, United States; 2Indian Institute of Technology Dharwad, India

Session A08: Control of Renewable Energy Systems

1472 | Sliding Mode Control Based Energy Harvesting System for Low Power Applications
Honorio Martinez Sarmiento1, Maen Marji1, Cheaheng Lim1, Jonghoon Kim1, Nan Wang1, Woonki Na1
1California State University Fresno, United States; 2Chungnam National University, Korea

Universidad Tecnológica de la Mixteca, Mexico

1200 | A New Kalman-Filter-Based Harmonic Current Suppression Method for the Virtual Oscillator Controlled Voltage Source Converters with LCL
Siyi Luo1, Weimin Wu1, Koutroulis Efthychios2, Frede Blaabjerg3, Henry Shu-Hung Chung4
1Shanghai Maritime University, China; 2Technical University of Crete, Greece; 3Aalborg University, Denmark; 4City University of Hong Kong, China

1300 | Transient Stability Enhancement for Virtual Synchronous Generator by Combining Direct Power Control
Xuejiao Zhong1, Yutao Lou2, Tiliang Wen1, Donghai Zhu1, Xudong Zou1, Xiang Guo1
1Huazhong University of Science and Technology, China; 2Shanghai Institute of Satellite Engineering, China

2334 | Power-Synchronized Current Control for Grid-Connected Converters
Xiao Wang, Xiongfei Wang
Aalborg University, Denmark

1587 | A New Control Strategy Based on PLL to Enhance System Stability under Varying Output Power in Weak Grids
Junliang Liu1, Xiong Du1, Yuming Liu2, Dengfeng Li2, Bo Zhang1, Chenghui Tong1
1Chongqing University, China; 2State Grid Chongqing Electric Power Company, China

1323 | 240°-Clamped PWM in Three Phase Grid-Connected PV Converter Application
Hafsa Qamar, Haleema Qamar, Rajapandian Ayyanar
Arizona State University, United States

Session A09: Grid Integration of Renewables

1656 | An Enhanced Double Quasi-PR Controller for Grid-Side Inverter with Long Transmission Cable
Weibiao Wu1, Ke Hu2, Ming Zhang1, Guijing Han1
1Wuhan Textile University, China; 2Huazhong University of Science and Technology, China

1066 | Circulating Current Analysis of Paralleled Grid-Connected Inverters Based on the Multi-Frequency Model
Liguo Wu, Xinbo Ruan, Zhiheng Lin, Hao Zhang
Nanjing University of Aeronautics and Astronautics, China
1647 | Comparison of Grid-Forming Converter Control Strategies
Anant Narula, Massimo Bongiorno, Mebtu Beza
Chalmers University of Technology, Sweden

2252 | Dynamic Impact of Voltage-Dependent Current Injection on Fault-Ride-Through of Grid-Following Converters
Xinshuo Wang¹, Heng Wu¹, Xiongfei Wang¹, Laurids Dall², Jun Bum Kwon³
¹Aalborg University, Denmark; ²Energinet, Denmark; ³Ørsted, Denmark

1199 | A New Type of Three-Phase Asymmetric LCL Power Filter for Grid-Tied Voltage Source Inverter
Weimin Wu¹, Yaozhong Zhang¹, Henry Shu-Hung Chung², Frede Blaabjerg³
¹Shanghai Maritime University, China; ²City University of Hong Kong, China; ³Aalborg University, Denmark

1709 | Analysis of Overmodulation in Power Synchronization-Based Voltage Source Converters
Federico Cecati¹, Sante Pugliese¹, Marco Liserre¹, Xiongfei Wang², Frede Blaabjerg²
¹Christian-Albrechts-Universität zu Kiel, Germany; ²Aalborg University, Denmark

1428 | Empirical Evaluation of GPS Clock Accuracy for Isochronous Droop-Based Inverters
Toby Meyers, Barry Mather
National Renewable Energy Laboratory, United States

Session A10: Wind Energy Systems

1536 | Permanent Magnet Generators for Wind Application: An Analytical Investigation
Seyed Payam Emami¹, Emad Roshandel², Amin Mahmoudi², Samad Taghipour Boroujeni¹, Solmaz Kahourzade³
¹Shahrekord University, Iran; ²Flinders University, Australia; ³University of South Australia, Australia

2298 | Aggregation of Wind Turbine Grid-Side Inverters by Voltage Angle and Cable Resonance Compensation
Zichao Zhou¹, Xiongfei Wang¹, Yin Sun²
¹Aalborg University, Denmark; ²Shell Global Solutions International B.V., The Netherlands

1393 | Research on Dynamic Reactive Power Coordinated Control Strategy of Doubly-Fed Wind Turbine Based on Improved Genetic Algorithm
Sen Cui¹, Xiangwu Yan¹, Ruibo Li¹, Wenfei Chang¹, Waseem Aslam²
¹North China Electric Power University, China; ²University of Sargodha, Pakistan

1485 | Power-Electronics-Based Mission Profile Emulator for DFIG-Based Wind Power Generation System
Huichao Ge, Ke Ma
Shanghai Jiao Tong University, China

1707 | Electromagnetic Study of Direct-Driven Wind Turbine Generators by Coupled Field- Circuit Simulations and Full-Scale Bench Tests
Christoph Müller¹, Fabian Müller¹, Andreas Thul¹, Kay Hameyer¹, Christoph Meier²
¹RWTH Aachen University, Germany; ²Wobben Research and Development GmbH, Germany

2173 | Comparison of Active and Passive 9-Phase Wind Turbine Conversion System for an all DC Grid
Omid Beik¹, Ahmad S. Al-Adsani²
¹McMasters University, Canada; ²Public Authority for Applied Education and Training, Kuwait

2299 | Dynamic Model Validation and Harmonic Stability Analysis of Offshore Wind Power Plants
Zichao Zhou¹, Xiongfei Wang¹, Fangzhou Zhao¹, Jan R. Svensson², Lukasz Kocewiak³, Mikkel Peter Sidoroff Gryning¹, Aravind Mohanaveeramani²
¹Aalborg University, Denmark; ²Power Grids Research Hitachi ABB Power Grids, Sweden; ³Electrical Systems Ørsted Offshore A/S, Denmark
### Session A11: Other Topics in Renewables

1139 | An Amplitude-Modulated Pseudo-Random Binary Sequence Approach to Broadband Impedance Spectroscopy for Photovoltaic Module System Identification  
Linda Shelembe, Paul Barendse  
*University of Cape Town, South Africa*

1140 | A Quantitative Feedback Theory Approach to Converter-Based Broadband Impedance Spectroscopy for Online Condition Monitoring of Photovoltaic Modules  
Linda Shelembe, Paul Barendse  
*University of Cape Town, South Africa*

1368 | Light Intensity Modulation and Two-Port Network Analysis of Dynamic Response of Photovoltaic Module  
Thomas Link, Sean Youngblood, Lauren Boulay, S.M. Rakiul Islam, Eric Donkor, Sung-Yeul Park  
*University of Connecticut, United States*

1281 | A Traction Inverter Design for Increasing the DC Link Voltage in Electric Vehicles  
Hui Zhang  
*State University of New York at Oswego, United States*

1088 | HVDC Transmission of Offshore Wind Farm Using Current-Source Actively Commutated Converter with Very-Low-Capacity AC Network  
Zixin Li\(^1,2\), Kedong Luan\(^1,2\), Fei Xu\(^1,2\), Fanqiang Gao\(^1,2\), Cong Zhao\(^1,2\), Ping Wang\(^1,2\), Yaohua Li\(^1,2\)  
\(^1\)Chinese Academy of Sciences, China; \(^2\)University of Chinese Academy of Sciences, China

1254 | Online Condition Monitoring of Fuel Cells (FC) by Implementing Electrical Impedance Spectroscopy Using a Switch-Mode DC-DC Converter  
Surprise Mahlangu, Paul Barendse  
*University of Cape Town, South Africa*

2294 | Power Switch Open-Circuit Fault-Diagnosis Based on a Shallow Long-Short Term Memory Neural Network: Investigation of an Interleaved Buck Converter for Electrolyser Applications  
Rahul Kumar\(^1\), Shanal Kumar\(^1\), Giansalvo Cirrincione\(^2\), Maurizio Cirrincione\(^1\), Damien Guilbert\(^3\), Krishnil Ram\(^1\), Ali Mohammadi\(^1\)  
\(^1\)The University of the South Pacific, Fiji; \(^2\)University of Picardy Jules Verne, France; \(^3\)University of Lorraine, France

### Session A12: Architectures for Renewable and Hybrid Renewable Energy Systems

2170 | Three-Port Multilevel Converter for Hourly Dispatching Solar PV Power with Battery Energy Storage System  
Pranoy Roy, JiangBiao He, Aaron Cramer  
*University of Kentucky, United States*

2513 | Synchronizing Control of Wind Turbine Driven Doubly Fed Induction Generator System with DG in Remote Area Involving Solar PV-Battery Energy Storage  
Sambasivaiah Puchalapalli, Bhim Singh  
*Indian Institute of Technology Delhi, India*

2459 | Smoothing of PV Output Power in Grid-Tied Energy Storage System with Model Predictive Control and Battery Lifetime Consideration  
Md Safayatullah, Qun Zhou, Issa Batarseh  
*University of Central Florida, United States*
1973 | A Direct AC/AC Modular Multilevel Cascade Converter Based on Bridge Cells with Distributed Energy Resources
Bruno E. de O.B. Luna1, Cursino B. Jacobina2, Alexandre C. Oliveira2, Nustenil S.M.L. Marinus3  
1Federal Rural University of the Semi-arid Region, Brazil; 2Federal University of Campina Grande, Brazil; 3Federal Institute of Education, Science and Technology of Ceará, Brazil

2188 | Optimization of Reactive Power Distribution in Series PV-Battery-Hybrid Systems
Yiwei Pan1, Ariya Sangwongwanich1, Yongheng Yang2, Frede Blaabjerg1  
1Aalborg University, Denmark; 2Zhejiang University, China

1287 | Modular Differential Power Processing Architecture Utilizing Isolated Bus to Virtually Unify Photovoltaic Panel Characteristics in Large-Scale Systems
Takumi Suzuki, Masatoshi Uno  
Ibaraki University, Japan

Session A13: Renewable Energy and Storage Systems

1695 | An Efficient and Compact Single-Stage High-Frequency-Link Medium Voltage AC to DC Converter
Harisyam PV., Dibakar Das, Kaushik Basu  
Indian Institute of Science, India

1663 | Impact of Partial Power Processing Dual-Active Bridge Converter on Li-Ion Battery Storage Systems
Hamzeh Beiranvand, Felix Hoffmann, Frederik Hahn, Marco Liserre  
Christian-Albrechts-Universität zu Kiel, Germany

2523 | Modular Wireless Power Transmission for Photovoltaic Subpanel System
Yue Zheng, Zeyu Cheng, Chang Liu, Hongling Liu, Mahshid Amirabadi, Brad Lehman  
Northeastern University, United States

1664 | Design of an Isolated DC-DC Converter for PV Micro-Inverters with Planar Transformer and PCB Integrated Winding
Tobias Manthey, Tobias Brinker, Jens Friebel  
Leibniz Universität Hannover, Germany

1803 | Hardware and Control Design Considerations for a Mobile 1 MW Input-Series Output-Parallel (ISOP) DC-DC Converter in Medium Voltage Range
David Tatusch1, Jens Friebel1, Anton Gorodnichev2, Daniel Haake3, Fabian Schnelle2, Marco Jung3  
1Leibniz Universität Hannover, Germany; 2Fraunhofer Institute for Energy Economics and Energy System Technology, Germany; 3Bonn-Rhein-Sieg University of Applied Sciences, Germany

2437 | Optimized AC/DC Dual Active Bridge Converter Using Monolithic SiC Bidirectional FET (BiDFET) for Solar PV Applications
North Carolina State University, United States

Session A14: Applications for Renewable and Sustainable Energy Systems

2233 | Reliable Method for the Measurement of Diffusion Capacitance in Solar Photovoltaic Cells
Alireza Ramyar, Yasir Altheyabi, Al-Thaddeus Avestruz  
University of Michigan, United States

1593 | A Lead-Lag Filter for Virtual Synchronous Machines with Improved Electromechanical Damping
Fabio Mandrile, Vincenzo Mallemaci, Enrico Carpaneto, Radu Bojoi  
Politecnico di Torino, Italy
**2026 | Multisampling Based Grid Impedance Estimation for Two-Cell Interleaved Three-Phase Inverters**
Shan He, Dao Zhou, Xiongfei Wang, Frede Blaabjerg
Aalborg University, Denmark

**2424 | Levelized Cost of Energy Optimization in Hybrid PV Plants by Energy Storage for Ramp-Rate Control Operation**
Irene Peláez, Cristian Blanco, Andrés Suarez, Ángel Navarro, Pablo García
University of Oviedo, Spain

**1363 | Control Strategy to Attenuate Voltage Oscillations under Unbalanced Power Distribution in Large Scale Photovoltaic Cascaded Multilevel Converters**
Yuniel León-Ruíz, Mario González-García, Ricardo Álvarez-Salas, Víctor Cárdenas, Rosa Iris Viera-Díaz
Universidad Autónoma de San Luis Potosí, Mexico

---

**Topic B: Smart Grid and Utility Applications**

**Session B01: Power Converters for Distributed Resources and Microgrids**

**1924 | An Isolated Voltage Injection Based Hybrid Circuit Breaker for MVDC Applications**
Abdul Basit Mirza, Yalda Azadeh, Hongwu Peng, Fang Luo
Stony Brook University, United States

**2227 | Solid State Circuit Breaker Design with Discrete SiC MOSFETs for Aircraft Electrification Application**
Piranavan Suntharalingam, Armen Baronian
Eaton, United States

**2134 | Modeling of Solid-State Circuit Breaker during Current Interruption Phase**
Dehao Qin¹, Di Zhang², Chuanyang Li³, Dong Dong⁴, Yang Cao⁵, Zheyu Zhang¹
¹Clemson University, United States; ²Naval Postgraduate School, United States;
³University of Connecticut, United States; ⁴Virginia Polytechnic Institute and State University, United States

**1671 | Control of a Three-Phase Four-Wire Modular Multilevel Converter as a Grid Emulator in Fault Scenarios**
Ming Jia, Shenghui Cui, Katharina Hetzenecker, Jingxin Hu, Rik W. De Doncker
RWTH Aachen University, Germany

**2011 | A New Fully Soft-Switched, Single-Stage Bidirectional LLC Resonant Based AC/DC Converter for Hybrid Micro-Grid with Active Ripple Energy Storage**
Parham Mohamadi, John Lam
York University, Canada

**1975 | 3-Phase Back to Back Active Power Filter for a Multi-Generator Power System with Reduced DC-Link Capacitor**
Jongwan Kim¹, Jih-Sheng Lai²
¹Texas Instruments, United States; ²Virginia Polytechnic Institute and State University, United States

**2301 | Residual Power Transfer Capability Analysis of an MMC-SST under Submodule IGBT Open-Circuit Fault**
Jiajie Zang¹, Jiacheng Wang¹, Jianwen Zhang¹, Jianqiao Zhou², Jiahu Guo², Dongmin Xi³
¹Simon Fraser University, Canada; ²Shanghai Jiao Tong University, China; ³Inner Mongolia University of Technology, China
Session B02: V2G and G2V

1181 Distributed Control Design for V2G in DC Fast Charging Stations
Asal Zabetian-Hosseini, Geza Joos, Benoit Boulet
McGill University, Canada

2500 | A New Modular Level-2 PEV Charger for Plug-In Electric Vehicle: Design and Implementation
Laith Alkhawaldeh, Lingli Gong, Mohamed Youssef
Ontario Tech University, Canada

2098 | Electric Vehicle Battery as Energy Storage Unit Consider Renewable Power Uncertainty
Qiyun Dang, Di Wu, Benoit Boulet
McGill University, Canada

1339 | Passenger Weight Detection by Air Suspension Pressure Monitoring for Smart Grid Integration of Electric Buses
Utz Spaeth, Heiko Fechtner, Michele Weisbach, Alexander Popp, Benedikt Schmuelling
University of Wuppertal, Germany

Session B03: Control of DC Microgrids

1950 | A Plug-and-Play Capable Multi-Agent Network for Distributed Consensus-Based Operation in DC Power Systems
Anas Alseyat, Md Habib Ullah, Jae-Do Park
University of Colorado Denver, United States

1777 | A Power Electronics-Based Power HIL Real Time Simulation Platform for Evaluating PV-BES Converters on DC Microgrids
Isuru Jayawardana, Carl Ngai Man Ho
University of Manitoba, Canada

1853 | Tertiary Control Method for Droop Controlled DC-DC Converters to Ensure Bounded Voltages in DC Microgrids
Shrivatsal Sharma, Vishnu Mahadeva Iyer, Subhashish Bhattacharya, Jun Kikuchi, Ke Zou
1North Carolina State University, United States; 2Indian Institute of Science, India; 3Ford Motor Company, United States

2025 | Weighted Dynamic Aggregation Modeling of DC Microgrid Converters with Droop Control
Aida Afshar Nia, Navid Shabanikia, S. Ali Khajehoddin
University of Alberta, Canada

2495 | MAS-Based Distributed Load Restoration in Resilient Networked DC Microgrids Systems
Md Habib Ullah, Jae-Do Park
University of Colorado Denver, United States

Session B04: Grid Intelligence for Unique Loading Scenarios

1149 | Digital Twin for Self-Security of Smart Inverter
Tareq Hossen, Mehmetcan Gursoy, Behrooz Mirafzal
Kansas State University, United States

1348 | Comparative Investigation of System-Level Optimized Power Conversion System Architectures to Reduce LCOE for Large-Scale PV-Plus-Storage Farms
Zheng An, Rajendra Prasad Kandula, Deepak Divan
Georgia Institute of Technology, United States
<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2076</td>
<td>A Model-Based Short-Term Load Forecast Methodology for Aggregated Power Consumption of Thermostatically Controlled Appliances in DSM</td>
<td>Pegah Yazdkhasti, Chris P. Diduch</td>
<td>University of New Brunswick, Canada</td>
</tr>
<tr>
<td>1245</td>
<td>Review on the State-of-the-Art Operation and Planning of Electric Vehicle Charging Stations in Electricity Distribution Systems</td>
<td>Mehrdad Aghamohamad, Amin Mahmoudi, John K. Ward, Mohammed H. Haque</td>
<td>Flinders University, Australia; CSIRO, Australia; University of South Australia, Australia</td>
</tr>
<tr>
<td>1243</td>
<td>Recourse-Based BCD Robust Integrated Bidding Strategy for Multi-Energy Systems under Uncertainties of Load and Energy Prices</td>
<td>Mehrdad Aghamohamadi, Amin Mahmoudi, John K. Ward, Megan Sleep, Mohammed H. Haque</td>
<td>Flinders University, Australia; CSIRO, Australia; University of South Australia, Australia</td>
</tr>
<tr>
<td>1069</td>
<td>Multi-Terminal Soft Open Point with Anti-Islanding and Over-Current Protection Capability</td>
<td>Han Deng, Yang Qi, Jingyang Fang, Vincent Debusschere, Yi Tang</td>
<td>Nanyang Technological University, Singapore; Northwestern Polytechnical University; University of Kaiserslautern, Germany; Grenoble Institute of Technology, France</td>
</tr>
<tr>
<td>1221</td>
<td>Fault-Tolerant Distribution Network Enabled by Series Soft Open Point</td>
<td>Yang Qi, Han Deng, Yi Tang</td>
<td>Northwestern Polytechnical University, China; Nanyang Technological University, Singapore</td>
</tr>
<tr>
<td>1489</td>
<td>Reactive Power Allocation of PV Inverters for Voltage Support in Power Systems Based on Transactive Energy Approach</td>
<td>Paychuda Kritprajun, Joshua C. Hambrick, Leon M. Tolbert, Yunting Liu, Jiaojiao Dong, Lin Zhu, Qihuan Dong, Kevin Schneider</td>
<td>The University of Tennessee Knoxville, United States; Oak Ridge National Laboratory, United States; Pacific Northwest National Laboratory, United States</td>
</tr>
<tr>
<td>1892</td>
<td>Development of a Power Electronics-Based Testbed for a Flexible Combined Heat and Power System</td>
<td>Haiguo Li, Dingrui Li, Zihan Gao, Yiwei Ma, Zhe Yang, Jingxin Wang, Fred Wang</td>
<td>University of Tennessee Knoxville, United States; Oak Ridge National Laboratory, United States</td>
</tr>
<tr>
<td>1292</td>
<td>Optimal Sizing of Grid-Tied Residential Microgrids under Real-Time Pricing</td>
<td>Rahmat Khezri, Amin Mahmoudi, Mohammad Hassan Khooban, Nesimi Ertugrul</td>
<td>Flinders University, Australia; Aarhus University, Denmark; University of Adelaide, Australia</td>
</tr>
<tr>
<td>1742</td>
<td>Active and Reactive Power Distribution for Cascaded-H-Bridge Microinverters under Island Microgrid</td>
<td>Maohang Qiu, Mengxuan Wei, Shuai Yang, Xiaoyan Liu, Dong Cao</td>
<td>University of Dayton, United States</td>
</tr>
<tr>
<td>2007</td>
<td>Microgrid Light-Load Efficiency Improvement Based on Online-Inverter Detection</td>
<td>Ali Sheykhi, Nima Amouzegar Ashtiani, S. Ali Khajehoddin</td>
<td>University of Alberta, Canada</td>
</tr>
<tr>
<td>2267</td>
<td>Reliability/Cost-Based Power Routing in Power Electronic-Based Power Systems</td>
<td>Saeed Peyghami, Frede Blaabjerg</td>
<td>Aalborg University, Denmark</td>
</tr>
<tr>
<td>1835</td>
<td>Quickest Detection of Series Arc Faults on DC Microgrids</td>
<td>Kaushik Gajula, Vu Le, Xiu Yao, Shaofeng Zou, Luis Herrera</td>
<td>University at Buffalo, United States</td>
</tr>
</tbody>
</table>
Session B06: Smart Buildings and Energy Management Strategies

1051 | A Novel Solar Harvesting Modular Wireless Sensor Mote for Green House Applications: Design & Implementation
Lingli Gong, Anshuman Sharma, Jordan Henry, Mohamed Youssef
Ontario Tech University, Canada

1326 | Smart Microgrid Architecture for Home Energy Management System
Majed Shakir, Yevgen Biletiskiy
University of New Brunswick, Canada

1902 | Generalized Energy Storage Model-in-the-Loop Suitable for Energy Star and CTA-2045 Control Types
Huangjie Gong¹, Evan S. Jones¹, A.H.M. Jakaria², Aminul Huque², Ajit Renjit², Dan M. Ionel²
¹University of Kentucky, United States; ²Electric Power Research Institute, United States

2017 | A Dynamic Load Control Strategy for an Efficient Building Demand Response
Konrad Erich Kork Schmitt, Ilham Osman, Rabindra Bhatta, Mahtab Murshed, Manohar Chamana, Stephen Bayne
Texas Tech University, United States

2460 | Control Architectures of Solar-Powered HVAC Systems: A DC-DC Converter’s Perspective
Niraja Swaminathan, Bailey Sauter, Yue Cao
Oregon State University, United States

2478 | Distributed Optimal Scheduling in Community-Scale Microgrids
Maitreyee Marathe, Giri Venkataramanan
University of Wisconsin Madison, United States

1401 | Energy Management and Optimal Planning of a Residential Microgrid with Time-of-Use Electricity Tariffs
Rahmat Khezri¹, Amin Mahmoudi¹, Mohammed H. Haque², Kaveh Khalilpour³
¹Flinders University, Australia; ²University of South Australia, Australia; ³University of Technology Sydney, Australia

1714 | Capacity Optimization and Optimal Placement of Battery Energy Storage System for Solar PV Integrated Power Network
Hassan I. Alhammad, Khalid A. Khan, Fahad Alismail, Muhammad Khalid
King Fahd University of Petroleum and Minerals, Saudi Arabia

Session B07: Stability and Power Quality

1374 | Impedance Modeling and Analysis of Grid Side Sampling Modular Multilevel Converter
Bo Zhang¹, Xiong Du¹, Jingbo Zhao², Jiapei Zhou³, Cheng Qian¹, Chengmao Du¹
¹Chongqing University, China; ²State Grid Jiangsu Electric Power Co., Ltd., China; ³Global Energy Interconnection Research Institute, China

1398 | Transient Modeling of Phase-Locked Loop and its Applications in a Multi-VSCs Grid-Connected System
Han Yan, Meng Huang, Xikun Fu, Yingjie Tang, Ju Sheng, Xiaoming Zha
Wuhan University, China

1486 | A New Impedance-Based Modeling and Stability Analysis Approach for Power Oscillations between Grid-Forming Inverters
Hanchao Liu, Zhe Chen, Maozhong Gong, Philip Hart, Yichao Zhang, Yukai Wang
GE Research, United States
Technical Program

1142 | Utilization of Local Phasor Measurements for Interarea-Oscillation Damping with Utility-Scale PV Plant
Mayur Basu, Jinho Kim, Robert M. Nelms, Eduard Muljadi
Auburn University, United States

2336 | Frequency Selective Damping of Sub-Synchronous Oscillations for Grid-Forming Power Converters
Ngoc Bao Lai¹, Leonardo Marin², Andrés Tarrasó¹, Gregory N. Baltas¹, Pedro Rodriguez¹
¹Luxembourg Institute of Science and Technology, Luxembourg; ²Universitat Politècnica de Catalunya, Spain

1228 | Extremum Seeking Control Based Resonant Frequency Estimation for a Grid-Tied Inverter with LCL Filter
Yuheng Wu¹, Mohammad Mahmud¹, Yue Zhao¹, Radha Krishna Moorthy², Madhu Sudhan Chintahavali²
¹University of Arkansas, United States; ²Oak Ridge National Laboratory, United States

2250 | Impedance Analysis of Voltage Source Converter Based on Voltage Modulated Matrix
Chao Wu¹, Xiaoling Xiong², Frede Blaabjerg¹
¹Aalborg University, Denmark; ²North China Electric Power University, China

Session B08: Control of Distributed Resources and Microgrids

1249 | Variable Step Size Modified Clipped Least Mean Square Adaptive Control for Power Quality Improvement for a Solar PV-BS Based Microgrid with Seamless Mode Transfer Capability
Vivek Narayanan, Bhim Singh
Indian Institute of Technology Delhi, India

1909 | Secondary Voltage and Frequency Regulation for Grid Re-Synchronization in Microgrid with Unified Virtual Oscillator Controlled Multi-Port Converters
Md Rashed Hassan Bipu, M.A. Awal, Siye Cen, Salina Zabin, Mehnaz Akhter Khan, David Lubkeman, Iqbal Husain
North Carolina State University, United States

2184 | Asymmetrical Voltage Support Control of Three-Phase Four-Wire Inverters with Zero Active Power Oscillation during Grid Faults
Jun Ge¹, Zhikang Shuai¹, Xia Shen¹, Yu Feng¹, Huimin Zhao¹, Yang Shen¹, Z. John Shen²
¹Hunan University, China; ²Illinois Institute of Technology, United States

2043 | Enhanced DC-Link Voltage Control in a Virtual Synchronous Generator-Based Building-to-Building Grid considering Islanded Mode Operation
Mhret Berhe Gebreemariam, Pablo Garcia Fernandez, Cristian Blanco Charro, Angel Navarro Rodriguez
University of Oviedo, Spain

2190 | Control Strategy for Multiple Residential Solar PV Systems in Distribution Network with Improved Power Quality
Yashi Singh, Bhim Singh, Sukumar Mishra
Indian Institute of Technology Delhi, India

1968 | Secant-Based Flexible Power Point Tracking Algorithm for Degraded Photovoltaic Systems
Anusha Kumaresan¹, Hossein Dehghani Tafti², Glen G. Farivar³, Nandha Kumar Kandasamy⁴, Josep Pou¹
¹Nanyang Technological University, Singapore; ²University of Western Australia, Australia; ³Singapore Institute of Technology, Singapore

2106 | Parameters Stability Region Analysis of Diesel Generation Forming Hybrid Islanded Microgrid with High Penetration of Renewable Energy
Xun Jiang¹, Meiqin Mao¹, Liuchen Chang¹, Peng Li², Yong Shi¹
¹Hefei University of Technology, China; ²North China Electric Power University, China
**Session B09: Control of Renewable Energy Resources**

1404 | **An Improved Proportional Resonant Controller for Current Harmonics Reduction and Power Ripples Mitigation of Self-Synchronized Grid-Tied PV System under Distorted Grid Voltages**  
Manash Kumar Mishra, V.N. Lal  
*Indian Institute of Technology (BHU), Varanasi, India*

1653 | **Control of Solar PV-Battery System to Limit in PCC Voltage Rise and for Power Quality Improvement**  
Gaurav Modi, Bhim Singh, Yashi Singh  
*Indian Institute of Technology Delhi, India*

1978 | **Review of Control Methods in Grid-Connected PV and Energy Storage System**  
Md Safayatullah, Reza Rezaii, Mohamed Tamasas Elrais, Issa Batarseh  
*University of Central Florida, United States*

1219 | **A Virtual SVPWM Based Power Control Scheme for Multi-Port DC-AC Converters in PV-Battery Hybrid Systems**  
Jiangfeng Wang¹, Kai Sun², Yunwei Li¹  
¹*University of Alberta, Canada; ²Tsinghua University, China*

2145 | **Active Disturbance Rejection Control of Doubly-Fed Induction Generators Driven by Wind Turbines**  
Matthew Penne¹, Wei Qiao¹, Liyan Qu¹, Lizhi Qu¹, Renke Huang², Qiuhua Huang²  
¹*University of Nebraska Lincoln, United States; ²Pacific Northwest National Laboratory, United States*

1257 | **A Per-Phase Power Controller allowing Smooth Transitions to Islanded Operation**  
Hossein Abedini, Tommaso Caldognetto, Paolo Mattavelli  
*University of Padova, Italy*

1605 | **An Improved Energy Hub Model for Physical Layer in Energy Router**  
Zilong Wang, Tong Liu, Wei Wang, Qicai Ren, Alian Chen  
*Shandong University, China*

**Session B10: Control of Grid-Tied Inverters**

1037 | **Complex Power Control Method for Grid-Forming Inverter in αβ-Domain**  
Ko Oue, Shunya Sano, Toshiji Kato, Kaoru Inoue  
*Doshisha University, Japan*

2417 | **Lyapunov Energy Function Based Direct Power Control of Synchronverters under Unbalanced Grid Voltage Conditions**  
Vikram Roy Chowdhury, Deepak Divan  
*Georgia Institute of Technology, United States*

2361 | **Resynchronization Strategy for a 200kVA Grid-Forming Power Converter**  
Andres Tarraso¹, Ngoc Bao Lai², Pedro Rodriguez²  
¹*Universitat Politècnica de Catalunya, Spain; ²Luxembourg Institute of Science and Technology, Luxembourg*

1455 | **Angle Droop Design for Grid-Forming Inverters considering Impacts of Virtual Impedance Control**  
Le Kong¹, Yaosuo Xue², Liang Qiao¹, Fred Wang¹²  
¹*University of Tennessee Knoxville, United States; ²Oak Ridge National Laboratory, United States*
2115 | Switched-Boost Common-Ground Five-Level (SBCG5L) Grid-Connected Inverter with Single-Stage Dynamic Voltage Boosting Concept
Reza Barzegarkhoo¹, Majid Farhangi¹, Ricardo P. Aguilera¹, Yam P. Siwakoti¹, Sze Sing Lee²
¹University of Technology Sydney, Australia; ²Newcastle University in Singapore, Singapore

1194 | An Enhanced Single-Phase Self-Tuning Filter Based Open-Loop Frequency Estimator for Weak Grid
Anant Kumar Vema¹, Hafiz Ahmed², Pedro Roncero-Sánchez³, Pradyumn Chaturvedi⁴
¹National Institute of Technology Hamirpur, India; ²Bangor University, United Kingdom;
³Universidad de Castilla-La Mancha, Spain; ⁴Visvesvaraya National Institute of Technology, India

1410 | Direct Charge Control Method for Mixed Conduction Mode (DCM and TPCM) Grid-Connected Inverter
Pu Zhao, Qingxin Guan, Yu Zhang
Huazhong University of Science and Technology, China

Session B11: Control of DC Microgrids

1939 | Comparative Study of Coordinated Photovoltaic and Battery Control Strategies on the Battery Lifetime in Stand-Alone DC Microgrids
Hein Wai Yan¹, Glen G. Farivar¹, Neha Beniwal¹, Naga Brahmendra Yadav Gorla¹, Hossein Dehghani Tafti², Salvador Ceballos³, Josep Pou⁴, Georgios Konstantinou⁴
¹Nanyang Technological University, Singapore; ²University of Western Australia, Australia;
³Basque Research and Technology Alliance, Spain; ⁴University of New South Wales, Australia

2029 | Model Predictive Control for Current Sharing and Voltage Balancing in DC Microgrids
Lalit Kishore Marepalli, Kaushik Gajula, Luis Herrera
University at Buffalo, United States

1913 | Control Strategy for Effective Battery Utilization in a Stand-Alone DC Microgrid with Solar Energy
Hein Wai Yan¹, Glen G. Farivar¹, Neha Beniwal¹, Naga Brahmendra Yadav Gorla¹, Hossein Dehghani Tafti², Salvador Ceballos³, Josep Pou⁴, Georgios Konstantinou⁴
¹Nanyang Technological University, Singapore; ²University of Western Australia, Australia;
³Basque Research and Technology Alliance, Spain; ⁴University of New South Wales, Australia

1026 | Distributed Linear State Observer (DLSO)-Based Distributed Secondary Control for DC Microgrids under False Signal Attacks
Yajie Jiang¹, Yun Yang², Siew-Chong Tan³, Shu-Yuen Ron Hui⁴
¹The University of Hong Kong, China; ²The Hong Kong Polytechnic University, China;
³Nanyang Technological University, Singapore; ⁴Imperial College London, United Kingdom

1439 | The Impact of PV Arrays Disturbances on the Performance of Droop Controllers in a DC Microgrid
Nilofar Ghanbari, Subhashish Bhattacharya
North Carolina State University, United States

2488 | Enhancing Distribution Grid Flexibility Using Active Power Distribution Node Converter Interfaces
Alvaro Cardoza, Alexis Kwasinski
University of Pittsburgh, United States

2415 | Feedback Linearization Based Direct Power Control of a Three-Phase Grid-Connected Inverter with Online Parameter Update
Vikram Roy Chowdhury, Deepak Divan
Georgia Institute of Technology, United States
Session B12: Microgrid Control

1919 | Design Power Control Strategies of Grid-Forming Inverters for Microgrid Application
Jing Wang
National Renewable Energy Laboratory, United States

2283 | An Enhanced Control Strategy of Bidirectional Interlinking Converters in a Hybrid AC/DC Microgrid
Qipeng Zheng, Fei Gao
Shanghai Jiao Tong University, China

2555 | Coordination of Protection and Ride-Through Settings for Islanded Facility Microgrids
Mark Vygoder¹, Farzad Banihashemi¹, Jacob Gudex¹, Robert M. Cuzner¹, Giovanna Oriti²
¹University of Wisconsin Milwaukee, United States; ²Naval Postgraduate School, United States

1966 | Event-Triggered Self-Learning Control Scheme for Power Electronics Dominated Grid
Mohsen Hosseinzadehtaher, Amin Y. Fard, Mohammad B. Shadmand
University of Illinois Chicago, United States

1795 | Optimal Separation Method of Dynamic Microgrid Operation
Xuefei Zhu, Jinho Kim, Eduard Muljadi, R. Mark Nelms
Auburn University, United States

2049 | Improved Delay Compensation in Communication-Based Hierarchical Control of a Low Voltage 3-Phase AC Microgrid Using a Secondary Control Based on Smith Predictor
Ángel Navarro-Rodríguez, Cristian Blanco, Pablo García, Mohammad Irfan Yousuf
University of Oviedo, Spain

1789 | Analysis of a Complex-Valued Droop Method in AC Microgrids with Complete Steady-State Frequency Compensation Using dq-Decomposition
Carlos Gómez-Aleixandre, Cristian Blanco, Andrés Suárez-González, Ángel Navarro-Rodríguez, Pablo García
University of Oviedo, Spain

Session B13: Solid State Transformers

1325 | Doubly-Fed Solid State Auto-Transformer (SSAT) Concept for Multi-Pulse Rectifiers
Farhana Islam, Harish S. Krishnamoorthy
University of Houston, United States

2004 | 500kVA Hybrid Solid State Transformer (HSST): Modelling and Control
Sanjay Rajendran, Soumik Sen, Zhicheng Guo, Alex Q. Huang
The University of Texas at Austin, United States

2397 | Design of Nanocrystalline Medium-Voltage Medium-Frequency Three-Phase Transformers for Grid-Connected Applications
Roderick Amir Gomez Jimenez¹, Germán G. Oggier², Roberto A. Fantino¹, Juan Carlos Balda¹, Yue Zhao¹
¹University of Arkansas, United States; ²Universidad Nacional de Rio Cuarto, Argentina

2556 | Insulation Design on High-Frequency Transformer for Solid-State Transformer
Zheqing Li, Yi-Hsun Hsieh, Qiang Li, Fred C. Lee, Chunyang Zhao
Virginia Polytechnic Institute and State University, United States

2569 | Virtual Prototyping Process for Assessment of Medium Voltage Grid-Connected Solid State Transformer Implementations
Rounak Siddaiah¹, Mark Vygoder¹, Robert M. Cuzner¹, Juan C. Ordonez², Mauricio B. Chagas²
¹University of Wisconsin Milwaukee, United States; ²Florida State University, United States
1721 | Design Considerations for a 50 kW Dual Bridge Series Resonant DC/DC Converter with Wide-Input Voltage Range for Solid-State Transformers
Pramod Apte¹, Siqi Lin¹, Lukas Fraeger², Jens Friebe¹
¹Leibniz Universität Hannover, Germany; ²BLOCK Transformatoren-Elektronik GmbH, Germany

1574 | Enhanced Current-Type P-HIL Interface Algorithm for Smart Transformers Testing
Sante Pugliese¹, Marco Liserre¹, Giovanni De Carne²
¹Christian-Albrechts-Universität zu Kiel, Germany; ²Karlsruhe Institute of Technology, Germany

Session B14: Power Converters for Distributed Resources and Microgrids

2086 | A New Common-Ground Switched-Boost Five-Level Inverter Suitable for Both Single and Three-Phase Grid-Tied Applications
Reza Barzegarkhoo, Yam P. Siwakoti, Ricardo P. Aguilera
University of Technology Sydney, Australia

1971 | Design and Development of a Multi-Port Converter for Marine Microgrid Applications
Md Rifat Kaisar Rachi, Siye Cen, Md Rashed Hassan Bipu, Mehnaz Akhter Khan, Iqbal Husain
North Carolina State University, United States

1387 | Multi-Port DC-DC Converter for Interconnecting Bipolar DC Buses of Bipolar DC Distribution System
Jun-Young Lee, Jee-Hoon Jung
Ulsan National Institute of Science and Technology, Korea

2438 | A Multiport DC Transformer to Enable Flexible Scalable DC as a Service
Mickael J. Mauger, Vikram Roy Chowdhury, Prasad Kandula, Deepak Divan
Georgia Institute of Technology, United States

1518 | A Transformerless Bidirectional Charger for Light Electric Vehicles
Jitendra Gupta, Bhim Singh, Muhammad Zarkab Farooqi
Indian Institute of Technology Delhi, India

2452 | Design Considerations of Three Phase Active Front End Converter for 13.8 kV Asynchronous Microgrid Power Conditioning System enabled by Series Connection of Gen-3 10 kV SiC MOSFETs
Nithin Kolli, Sanket Parashar, Raj Kumar Kokkonda, Anup Anurag, Ashish Kumar, Subhashish Bhattacharya, Victor Veliadis
North Carolina State University, United States

1016 | Design of the Hybrid Flexible Power Supply System for AC Electric Arc Furnace
Chongbin Zhao, Qirong Jiang
Tsinghua University, China

1624 | An Ultra-Low Weight Bidirectional Back End PFC Topology
Alex Sanchez, Asier Garcia-Bediaga, Itziar Alzuguren, Iñigo Zubitur, Alejandro Rujas
Ikerlan Technology Research Centre (BRTA), Spain

Session B15: High Power, Power Electronic Systems for Utility Applications

1911 | Solid State Transformers as Enhanced Smart Inverters for Power Quality Improvement in Active Distribution Networks
Javad Khodabakhsh, Gerry Moschopoulos
Western University, Canada
1044 | Continuous Operation of Wind Power Plants under DC Line Faults in Multi-Circuit HVDC Transmission System
Mitsuyoshi Enomoto¹, Kenichiro Sano¹, Junya Kanno², Junichi Fukushima²
¹Tokyo Institute of Technology, Japan; ²Tokyo Electric Power Company Holdings, Japan

2090 | A New Delta Hybrid Series STATCOM and DC Capacitor Voltage Balance Using Zero-Sequence Current
Ibhan Chand Rath, Anshuman Shukla
Indian Institute of Technology Bombay, India

2291 | Inductive Operation of the Low-Capacitance StatCom Using Modular Filter Inductor
Glen G. Farivar¹, Christopher D. Townsend¹, Hossein Dehghani Tafti², Ezequiel Rodriguez¹, Josep Pou¹, Branislav Hredzak¹
¹Nanyang Technological University, Singapore; ²University of Western Australia, Australia; ³University of New South Wales, Australia

1083 | A Bipolar Hybrid Circuit Breaker for Low-Voltage DC Circuits
Sudipta Sen¹, Shahab Mehraeen¹, Keyue Smedley²
¹Louisiana State University, United States; ²University of California Irvine, United States

1090 | Symmetries in Power Electronics
Jingyang Fang, Stefan M. Goetz
Duke University, United States

Session B16: Hybrid Transformers

1121 | Magnetic Integration and Modeling of Hybrid Distribution Transformer
Yibin Liu, Deliang Liang, Yhheng Wang, Lishi Zhang, Dawei Li, Yachen Gao, Zihao Wu, Chenxi Wang, Lutian Tang
Xian Jiaotong University, China

1255 | Multiple Protection Strategies for Hybrid Distribution Transformer Based on DC-Link Voltage Fault-Tolerant Control
Lishi Zhang, Deliang Liang, Qidong Wen, Hua Liu, Yibin Liu, Yachen Gao, Zihao Wu, Chenxi Wang, Lutian Tang
¹Xi’an Jiaotong University, China; ²State Grid Shaanxi Electric Power Research Institute, China

2287 | Autonomous Fail-Normal Switch for Hybrid Transformers
Emre Durna, Joseph Benzaquen, Rajendra Prasad Kandula, Deepak Divan
Georgia Institute of Technology, United States

1619 | Active Transformer Functionalities including an Energy Storage System
Jose David Vidal Leon¹, Andres Tarraso¹, Jose Ignacio Candela¹, Pedro Rodriguez²
¹Polytechnic University of Catalonia, Spain; ²Luxembourg Institute of Science and Technology, Luxembourg

1118 | Hybrid Smart Transformer for Enhanced Power System Protection Against DC with Advanced Grid Support
Moazzam Nazir¹, Johan H. Enslin¹, Klaehn Burkes²
¹Clemson University, United States; ²Savannah River National Laboratory, United States
### Topic C: Big Data, Machine Learning, Cyber Security and Design Automation

#### Session C01: Big Data, Machine Learning, Cyber Security

<table>
<thead>
<tr>
<th>Session Code</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2480</td>
<td>Intelligent Anomaly Mitigation in Cyber-Physical Inverter-Based Systems</td>
<td>Asad Ali Khan, Sara Ahmed, Omar A. Beg</td>
<td>University of Texas San Antonio, United States; University of Texas Permian Basin, United States</td>
</tr>
<tr>
<td>2084</td>
<td>Blockchain-Enabled Security Module for Transforming Conventional Inverters toward Firmware Security-Enhanced Smart Inverters</td>
<td>Bohyun Ahn, Gomanth Bere, Seerin Ahmad, Jinchun Choi, Taesic Kim, Sung-won Park</td>
<td>Texas A&amp;M University Kingsville, United States</td>
</tr>
<tr>
<td>1150</td>
<td>Load Power Estimation Using a Recurrent Neural Network for the Purpose of Computer Power Energy Efficiency Improvement</td>
<td>Shinichi Kawaguchi</td>
<td>Kanagawa Institute of Technology, Japan</td>
</tr>
<tr>
<td>2095</td>
<td>Real-Time Implementation of GPU-Accelerated Neural Network Learning for Dynamic System Identification</td>
<td>Nicholas Autobee, Amanda Rowsell, Patrick Bales-Parks, Jae-Do Park</td>
<td>University of Colorado Denver, United States</td>
</tr>
</tbody>
</table>

#### Session C02: Artificial Intelligence and Machine Learning

<table>
<thead>
<tr>
<th>Session Code</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1371</td>
<td>Efficient-ArcNet: Series AC Arc Fault Detection Using Lightweight Convolutional Neural Network</td>
<td>Kamal Chandra Paul, Tiefu Zhao, Chen Chen, Yunsheng Ban, Yao Wang</td>
<td>University of North Carolina Charlotte, United States; University of Central Florida, United States; Hebei University of Technology, China</td>
</tr>
<tr>
<td>1940</td>
<td>Real-Time DC Pulsed Power Load Monitoring Using Simplified k-NN Algorithm</td>
<td>Yue Ma, Atif Maqsood, Damian Oslebo, Keith Corzine</td>
<td>University of California Santa Cruz, United States; Dynapower Company, LLC, United States; Naval Sea Systems Command, United States</td>
</tr>
<tr>
<td>2224</td>
<td>Intelligent Prediction of States in Multi-Port Autonomous Reconfigurable Solar Power Plant (MARS)</td>
<td>Suman Debnath, Shruti Kulkarni, Catherine Schuman</td>
<td>Oak Ridge National Laboratory, United States</td>
</tr>
<tr>
<td>2474</td>
<td>Detection of Stator Fault in Synchronous Reluctance Machines Using Shallow Neural Network</td>
<td>Siwan Shachin Narayan, Rahul R. Kumar, Giansalvo Cirrincione, Maurizio Cirrincione</td>
<td>The University of the South Pacific, Fiji; University of Picardy Jule Verne, France</td>
</tr>
<tr>
<td>1683</td>
<td>A Machine Learning Based Method to Efficiently Analyze the Cogging Torque under Manufacturing Tolerances</td>
<td>Andrea Reales, Werner Jara, Gabriel Hermosilla, Carlos Madariaga, Juan Tapia, Gerd Bramerdorfer</td>
<td>Pontificia Universidad Católica de Valparaiso, Chile; Universidad de Concepcion, Chile; Johannes Kepler University Linz, Austria</td>
</tr>
</tbody>
</table>
Session C03: Other Topics in Big Data, Machine Learning, Cyber Security and Design Automation

1702 | Fast and Accurate Inductance Extraction for Power Module Layout Optimization Using Loop-Based Method
Quang Le, Imam Al Razi, Yarui Peng, H. Alan Mantooth
University of Arkansas, United States

2554 | On the Explainability of Black Box Data-Driven Controllers for Power Electronic Converters
Subham Sahoo, Huai Wang, Frede Blaabjerg
Aalborg University, Denmark

1346 | Using Machine Learning Technology to Online Predict the Maximum Common Mode Current of Three-Phase Motor Drive Inverter
Ximu Zhang¹, Yang Huang¹, Jared Walden¹, Hua Bai¹, Fanning Jin², Xiaodong Shi², Bing Cheng²
¹University of Tennessee Knoxville, United States; ²Mercedes-Benz R&D North America, Inc., United States

Session C04: Data Analysis for Batteries and Energy Storage

1528 | Comparative Analysis on the Electrical State-of-Health Degradation of 21700 LiNiCoAlO2 Based on Alternating and Direct Currents
Bongwoo Kwak¹, Myungbok Kim¹, Jonghoon Kim²
¹Korea Institute of Industrial Technology, Korea; ²Chungnam National University, Korea

2292 | Artificial Intelligence-Based Hardware Fault Detection for Battery Balancing Circuits
Kyoung-Tak Kim¹, Hyun-Jun Lee¹, Joung-hu Park¹, Gomanth Bere², Justin J. Ochoa², Taesic Kim²
¹Soongsil University, Korea; ²Texas A&M University Kingsville, United States

1882 | Fast and Robust Estimation of Lithium-Ion Batteries State of Health Using Ensemble Learning
Xin Sui, Shan He, Soren Byg Vilsen, Remus Teodorescu, Daniel-Ioan Stroe
Aalborg University, Denmark

2396 | Lifetime Modeling and Analysis of Aqueous Organic Redox-Flow Batteries for Renewable Energy Application
Zhongting Tang¹, Ariya Sangwongwanich¹, Yongheng Yang², Charlotte Overgaard Wilhelmsen¹, Sebastian Birkedal Kristensen¹, Jens Laurids Sørensen¹, Jens Muff¹, Frede Blaabjerg¹
¹Aalborg University, Denmark; ²Zhejiang University, China

1513 | A Bidirectional Cell-to-Buffer Battery Equalizer at Boundary Conduction Mode with Constant On-Time Control
Yiqing Lu, Zhengqi Wei, Haoyu Wang
ShanghaiTech University, China

Session C05: Cyber Security and Cyber Attacks

1356 | Model-Based Cyber-Attack Detection for Voltage Source Converters in Island Microgrids
Jinan Zhang, Jin Ye, Lulu Guo
University of Georgia, United States

1865 | Detection and Mitigation of Cyber-Attacks against Power Measurement Channels Using LSTM Neural Networks
Mitchell Wilson, Hisham Mahmood, Joseph Giordano
Florida Polytechnic University, United States
<table>
<thead>
<tr>
<th>Session D01: Electric Drivetrains</th>
</tr>
</thead>
</table>
| **1195** | **Rule-Based Energy Management Strategy of a Power-Split Hybrid Electric Vehicle with LSTM Network Prediction Model**  
Helia Jamali, Yue Wang, Yuhang Yang, Saeid Habibi, Ali Emadi  
McMaster University, Canada |

| **2171** | **Reconfigurable Cascaded Multilevel Converter: A New Topology for EV Powertrain**  
Giulia Tresca¹, Riccardo Leuzzi¹, Andrea Formentini², Luca Rovere³, Norma Anglani¹, Pericle Zanchetta¹,³  
¹Università di Pavia, Italy; ²University of Genoa, Italy; ³University of Nottingham, United Kingdom |

| **1239** | **Electromagnetic and Direct-Cooling Analysis of a Traction Motor**  
John Wanjiuku¹, Lan Ge², Zhiyuan Zhang³, Kang Chang³, Chengtao Wu³, Fuliang Zhan²  
¹Siemens Digital Industries Software, Canada; ²Siemens Digital Industries Software, China |

| **1297** | **A Composite Converter with Reduced Power Electronics for Electric Powertrain Applications**  
Xiaokang Zhang, Jean-Yves Gauthier, Xuefang Lin-Shi  
INSA-Lyon, France |

| **2322** | **Impact of Current Profiling for NVH Mitigation on Switched Reluctance Machine Drive Accessories**  
Shuvajit Das¹, Anik Chowdhury¹, Md Ehsanul Haque¹, Md Tawhid Bin Tarek¹, Yilmaz Sozer¹, David Colavincenzo², Fernando Venegas³, Jeffrey Geither⁴  
¹The University of Akron, United States; ²Bendix Commercial Vehicle Systems, United States |

<table>
<thead>
<tr>
<th>Session D02: Battery Management Systems for Transportation</th>
</tr>
</thead>
</table>
| **1174** | **Model-Based Design Methodology for Capacitor-Based Equalization Circuits**  
Francesco Porpora¹, Mauro Di Monaco¹, Giuseppe Tomasso¹, Matilde D’Arpino²  
¹University of Cassino and Southern Lazio, Italy; ²The Ohio State University, United States |

| **2389** | **Predictive Battery SoC Control for Dual Propulsion Differential Four Wheel Drive Electric Vehicle**  
Utkal Ranjan Muduli¹, Khaled Al Jaafari¹, Ranjan Kumar Behera², Abdul R. Beig¹, Khalifa Al Hosani¹, Jamal Y. Alsawalhi¹  
¹Khalifa University, United Arab Emirates; ²Indian Institute of Technology Patna, India |

| **1768** | **A New Design Optimization Method for Dynamic Inductive Power Transfer Systems utilizing a Neural Network**  
Shuntaro Inoue, Reebal Nimri, Abhilash Kamineni, Regan Zane  
Utah State University, United States |
1498 | A High-Density 5kW 800V to 48V DC/DC Converter for Vehicle Applications
Xinyuan Du1, Fei Diao1, Yue Zhao1, Kevin Uvodich2, Nenad Miljkovic2
1University of Arkansas, United States; 2University of Illinois at Urbana-Champaign, United States

Session D03: Charging Techniques for Transportation

2028 | A Lightweight Multilevel Power Converter for Electric Aircraft Drivetrain
Samantha Coday, Nathan Ellis, Zitao Liao, Robert C.N. Pilawa-Podgurski
University of California Berkeley, United States

2507 | Electrical Insulation Design and Qualification of a SiC-Based Generator-Rectifier Unit (GRU) for High-Altitude Operation
Lakshmi Ravi1, Jiewen Hu1, Xingchen Zhao1, Dong Dong1, Rolando Burgos1, Sriram Chandrasekaran2, Saeed Alipour2, Richard Eddins3
1Virginia Polytechnic Institute and State University, United States; 2Raytheon Technologies, United States; 3GE Aviation, United States

1049 | A New Multilevel Inverter under Distributed Unbalance DC Voltage for Electric Vehicle Applications
Mohammad Bhuiya, Lingli Gong, Mohamed Z. Youssef
Ontario Tech University, Canada

Session D04: Transportation Electrification – 1

2501 | A Novel Buck-Boost Type DC-DC Converter Topology for Electric Vehicle Applications
Mohammad Saleh Khan1, Soumya Shubhra Nag1, Anandarup Das1, Changwoo Yoon2
1Indian Institute of Technology Delhi, India; 2Seoul National University of Science and Technology, Korea

1614 | Development of an Engine Starter Generator and Implementation of a Power Efficient Starting Procedure
Lukas Killingseder1, Wolfgang Gruber2, Alexander Burgstaller1, Martin Freudenthaler1
1BRP-Rotax GmbH & Co. KG, Austria; 2Johannes Kepler University Linz, Austria

1170 | Influence of the HV DC Bus Impedance on the Current Ripple Distribution in Electric Vehicles
Michael Schlüter, Marius Gentejohann, Sibylle Dieckerhoff
Technische Universität Berlin, Germany

Chao Jia, Junwei Cui, Wei Qiao, Liyan Qu
University of Nebraska Lincoln, United States

1509 | Design and Analysis of a Flexible Multi-Output Wireless Power Transfer System with Variable Inductor
Jin Zhao, Yonglin Zhang, Liang Qi
Jiangsu University of Science and Technology, China

1352 | Analysis and Mitigation of Oscillations in Inductive Power Transfer Systems with Constant Voltage Load and Pulse Density Modulation
Jiayu Zhou1, Giuseppe Guidi2, Kjell Ljokelsoy2, Jon Are Suul1,2
1Norwegian University of Science and Technology, Norway; 2SINTEF Energy Research, Norway
2311 | Low-Frequency Oscillations Analysis in AC Railway Networks Using Eigenmode Identification
Paul Frutos¹, Juan Manuel Guerrero¹, Iker Muniategui², Iban Vicente², Aitor Endeman², Fernando Briz¹
¹University of Oviedo, Spain; ²Ingeteam SA, Spain

1303 | Impedance Based Design Method for Interoperable Wireless Power Transfer Systems
Denis Kraus¹, Marius Hassler¹, Grant Covic², Hans-Georg Herzog¹
¹Technical University of Munich, Germany; ²The University of Auckland, New Zealand

Session D05: Transportation Electrification – 2

1738 | Development of a Fuel Cell Hybrid Electric Vertical Takeoff and Landing Aircraft Power Train
Mengxuan Wei¹, Maohang Qiu¹, Shuai Yang¹, Xiaoyan Liu¹, Jeff Taylor², Dong Cao¹
¹University of Dayton, United States; ²Event 38 Unmanned Systems, United States

2352 | Phase Collaborative Interleaving Method to Reduce DC-Link Current Ripple in Switched Reluctance Machine Drive
Md Ehsanul Haque¹, Anik Chowdhury¹, Shuvajit Das¹, Yilmaz Sozer¹, Fernando Venegas², David Colavincenzo²
¹The University of Akron, United States; ²Bendix Commercial Vehicle Systems, United States

2509 | Comparison of Medium-Voltage High-Frequency Power Inverters for Aircraft Propulsion Drives
Majid T. Fard, JiangBiao He
University of Kentucky, United States

2314 | Mechanical Performance of Transverse Flux Machines at High Speeds of Operation
Shuvajit Das¹, Anik Chowdhury¹, Teppei Tsuda², Naoto Saito², Subrata Saha³, Yilmaz Sozer¹
¹The University of Akron, United States; ²Aisin Corporation, Japan

1972 | Multilevel Traction Converter Topology with Medium Frequency Isolation
Bishwavijyoti Purkayastha, Tanmoy Bhattacharya
Indian Institute of Technology Kharagpur, India

Session D06: Transportation Electrification – 3

1501 | Load Management Strategy for DC Fast Charging Stations
Sony Susan Varghese¹, Geza Joos¹, Syed Qaseem Ali²
¹McGill University, Canada; ²OPAL-RT Technologies, Inc., Canada

2328 | Position Fault Detection and Failover Method for UAM PMSM Control
Taeyoen Lee¹, Heekwang Lee², Bonkil Koo¹, Kwanghee Nam¹
¹Pohang University of Science and Technology, Korea; ²Hyundai Motor Company, Korea

2430 | Fleet Speed Profile Optimization for Autonomous and Connected Vehicles
Mohammad Arifur Rahman, Md Ehsanul Haque, Yilmaz Sozer, Ali Riza Ozdemir
The University of Akron, United States

1247 | Design Methodology for a Transformerless Multilevel Inductive Power Transfer System
Jaehong Lee¹, Myung-Yong Kim², Seung-Hwan Lee¹
¹University of Seoul, Korea; ²Korea Railroad Research Institute, Korea

1013 | Current Balancing of a Multi-Phase Inverter for Wireless Power Transfer Systems Based on Mutually Negatively Coupled Inductors
Yiming Zhang¹, Yuanchao Wu¹, Shuxin Chen², Xin Li², Yi Tang²
¹Fuzhou University, China; ²Nanyang Technological University, Singapore
Session D07: Electric Vehicle Charging

2344 | Efficiency of Motor and Inverter Reconfigured as a Boost-Buck Connected Integrated BEV Charger
Erik Hoevenaars1, Marc Hiller2
1Robert Bosch GmbH, Germany; 2Karlsruhe Institute of Technology, Germany

1716 | Analysis and Design of a Multiport Converter Based Integrated On-Board Charger for Electric Vehicle Powertrains
Arka Basu, Subhajyoti Mukherjee
Indian Institute of Technology Bhubaneswar, India

1730 | Input Power Quality Control of Integrated On-Board Charger with Reduced DC-Link Capacitance
Muhammad Zarkab, Bhim Singh, B.K. Panigrahi
Indian Institute of Technology Delhi, India

1347 | A Flexible Resonant Converter Based Battery Charger with Power Relays
Yuqi Wei, Alan Mantooth
University of Arkansas, United States

1725 | A Two-Stage Standard On-Board Electric Vehicle Charger with Minimum Switch Count
Soumya Ranjan Meher, Rajeev Kumar Singh
Indian Institute of Technology (BHU), Varanasi, India

Session D08: EV Battery Management – 1

1107 | A Battery Capacity Estimation Method Using Surface Temperature Change under Constant-Current Charge Scenario
Jufeng Yang1, Yingfeng Cai1, Chris Mi2
1Jiangsu University, China; 2San Diego State University, United States

1288 | DAB Converter with Trapezoidal Wave Heating Capability for Lithium-Ion Battery of Electric Vehicles
Yuta Sasama, Masatoshi Uno
Ibaraki University, Japan

1632 | Stress-Constrained Fast Charging of Lithium-Ion Battery with Predictive Control
Hao Zhong, Hongwen He, Zhongbao Wei
Beijing Institute of Technology, China

1108 | State-of-Health Estimation for Lithium Iron Phosphate Batteries Based on Constant-Voltage Charge Data Using a Resistor-Inductor Network Based Equivalent Circuit Model
Jufeng Yang1, Yingfeng Cai1, Chris Mi2
1Jiangsu University, China; 2San Diego State University, United States

Session D09: EV Battery Management – 2

1554 | Multi-State Fusion Based Internal Short Circuit Fault Diagnostic for Lithium-Ion Battery
Jian Hu, Zhongbao Wei, Hongwen He
Beijing Institute of Technology, China

1039 | Parameter Identification of Lithium Battery Thermal Model Based on Two-Stage Forgetting Factor Least Square Method
Marui Li1, Chaoyu Dong1,2, Yunfei Mu1, Xiaohong Dong1, Jingming Cao1, Hongjie Jia1
1Tianjin University, China; 2Imperial College London, United Kingdom; 3Hebei University, China
## Technical Program

### Topic E: Power Converter Topologies

#### Session E01: DC-DC Non-Isolated – 1

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1727</td>
<td>The Effect of Pulsed Current on the Lifetime of Lithium-Ion Batteries</td>
<td>Xinrong Huang¹, Siyu Jin¹, Jinhao Meng², Remus Teodorescu¹, Daniel-Ioan Stroe¹</td>
<td>¹Aalborg University, Denmark; ²University of Electronic Science and Technology of China, China</td>
</tr>
<tr>
<td>2175</td>
<td>Sorting Selection Balancing Control for the Modular Multilevel DC/DC Converter in Battery Swapping Stations</td>
<td>Zhan Ma¹, Xiuqing Yi², Wei Li³, Feng Gao¹, Fujia Yu³</td>
<td>¹Shandong University, China; ²Shandong University of Traditional Chinese Medicine, China; ³State Grid Binzhou Power Supply Company, China</td>
</tr>
</tbody>
</table>

#### Session E02: DC-DC Isolated – 1

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2033</td>
<td>Modified Split-Phase Switching with Improved Fly Capacitor Utilization in a 48V-to-POL Dual Inductor Hybrid-Dickson Converter</td>
<td>Nathan M. Ellis, Robert C.N. Pilawa-Podgurski</td>
<td>University of California Berkeley, United States</td>
</tr>
<tr>
<td>2504</td>
<td>A Comparative Study of SiC JFET Super-Cascode Topologies</td>
<td>Lee Gill, Luciano A. Garcia Rodriguez, Jacob Mueller, Jason Neely</td>
<td>Sandia National Laboratories, United States</td>
</tr>
<tr>
<td>1692</td>
<td>Non-Isolated DC-DC Converter Implementations Based on Piezoelectric Transformers</td>
<td>Elaine Ng, Jessica D. Boles, Jeffrey H. Lang, David J. Perreault</td>
<td>Massachusetts Institute of Technology, United States</td>
</tr>
<tr>
<td>1134</td>
<td>A Single-Switch Capacitor Clamped Non-Resonant Linear Soft-Switching DC-DC Converter</td>
<td>Yangbin Zeng, Hong Li, Haitao Du, Zhidong Qiu, Ziqi Chen</td>
<td>Beijing Jiaotong University, China</td>
</tr>
<tr>
<td>1433</td>
<td>Voltage Gain Control of a Switched-Resonator Converter Based on the 2:1 Switched-Capacitor Cell</td>
<td>Dulika Nayanasiri, Yunwei Li</td>
<td>University of Alberta, Canada</td>
</tr>
</tbody>
</table>

#### Session E02: DC-DC Isolated – 1

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2321</td>
<td>Current Reduction by Tuning Split Ratio for a Three-Phase LLC Resonant Converter with Split Resonant Capacitors</td>
<td>Kazuto Takagi, Yuuki Aoyagi, Akiteru Chiba</td>
<td>GS Yuasa Infrastructure Systems Co., Ltd., Japan</td>
</tr>
<tr>
<td>1761</td>
<td>Design Optimization of PCB-Winding Matrix Transformer for 400V/12V Unregulated LLC Converter</td>
<td>Pranav Raj Prakash, Ahmed Nabih, Qiang Li</td>
<td>Virginia Polytechnic Institute and State University, United States</td>
</tr>
<tr>
<td>1129</td>
<td>Analytical Model of the Current Stress in Active-Bridge Active-Clamp Converter for More Electric Aircraft</td>
<td>Alejandro Fernandez-Hernandez¹, Asier Garcia-Bediaga¹, Irma Vilar¹, Gonzalo Abad²</td>
<td>¹Ikerlan Technology Research Centre (BRTA), Spain; ²Mondragon Unibertsitatea, Spain</td>
</tr>
<tr>
<td>1765</td>
<td>Bidirectional Resonant Frequency Tracking for CLLC Converters Based on Voltage Falling Edges</td>
<td>Jun Min, Martin Ordonez</td>
<td>The University of British Columbia, Canada</td>
</tr>
</tbody>
</table>
1163 | Controller-in-the-Loop of a Transformer Saturation Control for High-Power Three-Phase Dual-Active Bridge DC-DC Converters
Johannes Voss, Raphael Mencher, Philipp Joebges, Jan Mathé, Rik W. De Doncker
RWTH Aachen University, Germany

Session E03: DC-DC Isolated – 2

1711 | A Modified Soft-Switched Push-Pull Topology with Phase-Shift Modulation
Mandeep Singh Rana, Santanu K. Mishra, Hitesh Kumar
Indian Institute of Technology Kanpur, India

1474 | Low-Profile and High-Efficiency 3 kW 400 V-48 V LLC Converter with a Matrix of Four Transformers and Inductors for 48V Power Architecture for Data Centers
Ahmed Nabih, Qiang Li
Virginia Polytechnic Institute and State University, United States

2442 | Time-Domain Analysis of a Low Q Three-Phase Series Resonant Converter
Abirami Kalathy, Majid Pahlevani, Praveen Jain
Queen’s University, Canada

1849 | Optimized Synchronous Operation of Active-Clamp Bidirectional Flyback Based on GaN Devices for a Multi-Cell Multi-Port Structure
Asier Garcia-Bediaga, Ander Avila, Itziar Alzuguren, Alejandro Rujas
Ikerlan Technology Research Centre (BRTA), Spain

1984 | Control Strategies for Complete Soft-Switching of ICN Converters
Mausamjeet Khatua, Khurram K. Afridi
Cornell University, United States

Session E04: AC-DC Single Phase Converters – 1

1241 | A Four-Phase 5 kW Interleaved Totem-Pole PFC Platform Based on SiC FETs and Controlled by SA4041 Digital Power Processor
Gabriel Scarlatescu, Tanya Kirilova Gachovska, Tudor Lipan
Solantro Semiconductors Corp., Canada

2008 | A CCM Bridgeless Single-Stage Soft-Switching AC-DC Converter for EV Charging Application
Peyman Amiri¹, Wilson Eberle¹, Deepak Gautam², Chris Botting²
¹The University of British Columbia, Canada; ²Delta-Q Technologies Inc., Canada

1970 | An Interleaved Bridgeless AC/DC Stacked SiC Switches Based LLC Converter with Semi-Active Rectifiers for EV High Voltage Battery Systems
Mehdi Abbasi, John Lam
York University, Canada

1126 | Power Decoupling Method Using Input Filters in a Matrix Converter for Isolated AC-DC Converters Fed by Single- or Three-Phase Supply
Wataru Kodaka, Satoshi Ogasawara, Koji Orikawa
Hokkaido University, Japan
### Session E05: AC-DC and DC-AC Topologies and Control

| 2014 | A Truly Universal Bridgeless Single-Stage Soft-Switching AC/DC Converter for EV On-Board Charging Application  
Peyman Amiri\(^1\), Wilson Eberle\(^1\), Deepak Gautam\(^2\), Chris Botting\(^2\)  
\(^1\)The University of British Columbia, Canada; \(^2\)Delta-Q Technologies Inc., Canada |
| 2401 | A Multipurpose Converter for More Electric Aircraft with Hybrid AC-DC Electric Power System  
Javad Khodabakhsh, Gerry Moschopoulos  
Western University, Canada |
| 2557 | A MHz LLC Converter Based Single-Stage Soft-Switching Isolated Inverter with Hybrid Modulation Method  
Hao Wen\(^1\), Dong Jiao\(^1\), Jih-Sheng Lai\(^1\), Johan Strydom\(^2\), Bing Lu\(^2\)  
\(^1\)Virginia Polytechnic Institute and State University, United States; \(^2\)Texas Instrument, United States |
| 1959 | RF Band PWM Generator with High Efficiency and Wide-Band Control  
Tomohiro Yoneyama, Yu Hosoyama, Shohei Kobayashi, Itsuo Yuzurihara  
Kyosan Electric Mfg. Co., Ltd., Japan |

### Session E06: DC-AC Multiphase Converters

| 2528 | Model Predictive Control of a Double Stage AC-DC Converter for Grid-Interface of Vanadium Flow Batteries  
Savatore Riccardo Di Salvo\(^1\), Matteo Bulzi\(^1\), Jacopo Riccio\(^2\), Riccardo Leuzzi\(^1\), Pericle Zanchetta\(^1\), Norma Anglani\(^1\)  
\(^1\)University of Pavia, Italy; \(^2\)University of Nottingham, United Kingdom |
| 1555 | Volume Comparison of Passive Components for Hard-Switching Current- and Voltage-Source-Inverters  
Benedikt Riegler, Annette Mütze  
Graz University of Technology, Austria |
| 1740 | Bidirectional DC-AC Converter Using a High-Frequency Transformer with Multi-Frequency Decoupled Power Control  
Juan Zuniga, Marius Takongmo, Chatumal Perera, Vishwa Perera, John Salmon  
University of Alberta, Canada |
| 1728 | A Hybrid Active Neutral Point Clamped Converter Consisting of Si IGBTs and GaN HEMTs for Auxiliary Systems of Electric Aircraft  
Leon Fauth\(^1,2\), Christian Beckemeier\(^1,2\), Jens Friebe\(^1,2\)  
\(^1\)Technische Universität Braunschweig, Germany; \(^2\)Leibniz Universität Hannover, Germany |

### Session E07: Multilevel Converters – In Memory of Prof. Akira Nabae

| 2123 | Adaptive High-Frequency Injection and Control Loops Design for Flying Capacitor Passive Cross-Connected Modular Multilevel Converter Based Drive Systems  
Massimiliano Biason, Riccardo Breda, Mattia Iurich, Simone Mazzer, Roberto Petrella  
University of Udine, Italy |
| 1359 | Capacitor Voltage Ripple Suppression of the Switched Capacitor Modular Multilevel Converter  
Qichen Yang\(^1\), Robson Bauwelz Gonzatti\(^1,2\), Hamed Pourgharibshahi\(^1\), Fang Peng\(^1\)  
\(^1\)Florida State University, United States; \(^2\)Federal University of Itajuba, Brazil |
### Technical Program

**2475 | A Hybrid Binary Multilevel Cascaded Inverter for Medium-Voltage Applications**  
Jih-Sheng Lai¹, Bryan Gutierrez², Moonhyun Lee³, Chih-Shen Yeh³, Hao Wen¹, Dong Jiao¹, Zhengming Hou¹, Hsinche Hsieh¹  
¹Virginia Polytechnic Institute and State University, United States; ²Rivian, United States; ³Transphorm, United States

**1875 | Enhanced Interleaved PWM Scheme with Flux Compensation for Three-Parallel Connected Inverters**  
Chenhui Zhang, Marius Takongmo, John Salmon  
University of Alberta, Canada

**1828 | A Multi-Level Active Power Filter for Common-Mode Voltage Attenuation in Multi-Level Inverters**  
Dongwoo Han¹, Fang Z. Peng¹, Suman Dwari²  
¹Florida State University, United States; ²Raytheon Technologies Research Center, United States

#### Session E08: DC–DC Non-Isolated – 2

**2374 | A 48-to-12 V Cascaded Multi-Resonant Switched Capacitor Converter with 4700 W/in3 Power Density and 98.9% Efficiency**  
Ting Ge, Zichao Ye, Robert C.N. Pilawa-Podgurski  
University of California Berkeley, United States

**2286 | A Transformerless Composite Step-Down DC-DC Converter with Wide Input Voltage Range**  
Satyaki Mukherjee, Dragan Maksimović  
University of Colorado Boulder, United States

**1330 | A Multi-Phase Cascaded Series-Parallel (CaSP) Hybrid Converter for Direct 48 V to Point-of-Load Applications**  
Yicheng Zhu, Zichao Ye, Ting Ge, Rose Abramson, Robert C.N. Pilawa-Podgurski  
University of California Berkeley, United States

**2218 | High-Efficiency Operation of a Bidirectional Non-Isolated DC-DC Converter Based on Flying-Capacitor Converters**  
Kazuaki Tesaki, Makoto Hagiwara  
Tokyo Institute of Technology, Japan

**1747 | A 92.7%-Efficiency 30A 48V-to-1V Dual-Path Hybrid Dickson Converter for PoL Applications**  
Chen Chen, Jin Liu, Hoi Lee  
The University of Texas at Dallas, United States

**1868 | A Merged H-Bridge Based Switched Tank Converter for Front-End Voltage Regulator Modules**  
Jiawei Liang, Haoyu Wang, Hengzhao Yang  
ShanghaiTech University, China

#### Session E09: DC–DC Non-Isolated – 3

**1641 | A Hybrid Si/SiC Interleaved Bidirectional DC-DC Converter to Optimal Power Quality, Efficiency, and Cost Tradeoff**  
Kun Qu, Chao Zhang, Weibin Chen, Bo Hu, Jing Chen, Jun Wang  
Hunan University, China

**2023 | Analytic Model and Design Procedure of the Single-Secondary Trans-Inductor Voltage Regulator**  
Hang Shao, Tao Zhao, Dianbo Fu, Daocheng Huang, Jinghai Zhou  
Monolithic Power Systems, Inc., United States
1405 | **An Ultrahigh Step-Down DC-DC Converter Based on Switched-Capacitor and Coupled Inductor Techniques**
Longyang Yu¹, Chengzi Yang¹, Wei Mu¹, Fengtao Yang¹, Huaqing Li¹, Laili Wang¹, Yuquan Su², Chi Zhang²
¹Xi’an Jiaotong University, China; ²MiSiliconn Semiconductor Technologies Co., Ltd., China

1493 | **Input-Parallel-Output-Series Two-Stage Interleaved DC-DC Converter Using Coupled Inductors**
Yasuhiro Kodama, Hirotaka Koizumi
Tokyo University of Science, Japan

1651 | **Model-Free Predictive Control of Interleaved DC-DC Converters, Based on Ultra-Local Model, with Constant Switching Frequency**
Fernando Bento, Imed Jlassi, Antonio J. Marques Cardoso
University of Beira Interior, Portugal

1621 | **An Efficient and Compact Multi-Port Power Supply for Nano-Satellites**
Arnab Sarkar¹, Nachiketa Deshmukh¹, Pankaj Kumar¹, Sandeep Anand²
¹Indian Institute of Technology Kanpur, India; ²Indian Institute of Technology Bombay, India

Session E10: DC-DC Isolated – 3

1561 | **Exact Analysis of Parallel Resonant DC-DC Converter Using Phase Shift Modulation**
Vishal Anand A.G.¹, Anirban Pal², Ranganathan Gurunathan¹, Kaushik Basu²
¹Bloom Energy (I) Pvt Ltd., India; ²Indian Institute of Science, India

2010 | **Single-Stage Saturable Inductive-Link Half-Bridge Point of Load Converter**
Tuhin Subhra Sasmal, Kalyan Yenduri, Pritam Das
Binghamton University, United States

1436 | **Multiplexing-Based Flyback Converter for Multi-Port USB Power Delivery with True Power-Sharing**
Xingyue Tian¹, Han Cui¹, Lingxiao Xue¹
¹University of Tennessee Knoxville, United States; ²Oak Ridge National Laboratory, United States

1045 | **Transient Model and Elimination Method for DC Bias Current in Dual Active Bridge Converter**
Yangfan Chen, Yu Zhang
Huazhong University of Science and Technology, China

1220 | **Analysis of Synchronous-Rectification Switch Control for Active Class-E Rectifier**
Gwangyol Noh¹,², Gyu Cheol Lim³, Jung-Ik Ha¹
¹Seoul National University, Korea; ²Samsun Electronics, Korea; ³Seoul National University Electric Power Research Institute, Korea

1426 | **A Modified Three-Port Bidirectional LLC Resonant Converter for Renewable Power Systems**
Xi Chen, Issa Batarseh
University of Central Florida, United States

Session E11: DC-DC Isolated – 4

1603 | **Startup Strategy for ISOP Hybrid DC Transformer Featuring Low Current and Voltage Stress**
Wei Wang, Zhiwei Chen, Tong Liu, Jie Chen, Zilong Wang, Qicai Ren, Alian Chen
Shandong University, China

1549 | **Regenerative Snubber Based Bootstrapped Gate Driver Power Supply for Multiple Input Flyback Converter**
Arnab Sarkar¹, Aditya Aman², Sandeep Anand²
¹Indian Institute of Technology Kanpur, India; ²Indian Institute of Technology Bombay, India
Technical Program

1120 | A Constant Current Control Method with Improved Dynamic Performance for CLLC Converters
Huan Chen, Kai Sun, Languang Lu, Shuoqi Wang, Hongsheng Chong, Yudi Qin
Tsinghua University, China

1876 | A Switchable Rectifier-Based LLC Resonant Converter for Photovoltaic Applications
Fahad Alaql, Reza Rezaii, Sahin Gullu, Mohamed Tamasas Elrais, Issa Batarseh
University of Central Florida, United States

1349 | Multiple Operation Modes Based Stacked Structure LLC Converter for Very Wide Range Operation
Yuqi Wei, Alan Mantooth
University of Arkansas, United States

1718 | Five-Level T-Type Converter Based Fault-Tolerant Isolated DC-DC Topology Using WBG Devices
Amin Ashraf Gandomi¹, Leila Parsa¹, Keith Corzine¹, Vahid Dargahi²
¹University of California Santa Cruz, United States; ²University of Washington Tacoma, United States

Session E12: DC-DC Isolated – 5

1829 | A Novel Structure of Fully Soft-Switched DC-DC Converter with Frequency Doubling Feature for High-Density Power Conversion
Saikat Dey, Ashwin Chandwani, Ayan Mallik
Arizona State University, United States

2362 | A Boost and LLC Resonant-Based Three-Port DC-DC Converter
Fahad Alaql, Issa Batarseh
University of Central Florida, United States

2479 | Characteristics of Buck/Boost Operation in an Isolated DC-DC Converter Based on a Phase-Shift Controlled High-Frequency Inverter
Shohei Komeda, Masato Yamashita
Tokyo University of Marine Science and Technology, Japan

2074 | 400V-to-48V GaN Modular LLC Resonant Converter with Planar Transformer
Qingyun Huang¹, Qingxuan Ma¹, Alex Q. Huang¹, Michael de Rooij²
¹The University of Texas at Austin, United States; ²Efficient Power Conversion Corporation, United States

1470 | A Dual-Transformer-Based DC-DC Converter for Wide Voltage Gain and Wide ZVS Range by Utilizing a Sub-Optimal Simplified Control
Deliang Chen, Junjun Deng, Mingyang Li, Zhenpo Wang, Yang Li
Beijing Institute of Technology, China

1152 | Unidirectional Active-Passive Bridge (APB) DC-DC Converter Based on Resonant Control: FSM, PMW Operation with Soft-Switching Range and Step Power Control Method
Cao Anh Tuan, Takaharu Takeshita
Nagoya Institute of Technology, Japan

1122 | Boost Assist Control of LLC Resonant Converter for Wide Voltage Range by Use of Secondary-Side MOSFETs with ZVS Using Reverse Recovery Current of Body Diodes
Takae Shimada¹, Mizuki Nakahara¹, Takuya Ishigaki²
¹Hitachi, Ltd., Japan; ²Hitachi Industrial Equipment Systems Co., Ltd., Japan
### Session E13: DC–DC Isolated – 6

| 2439  | Novel Transformer with Variable Leakage and Magnetizing Inductances  
         | Angshuman Sharma, Jonathan W. Kimball  
         | Missouri University of Science and Technology, United States |
|-------|---------------------------------------------------------------------|
| 1148  | Effects of Parasitics on an Active Clamp Assisted Phase Shifted Full Bridge Converter Operation  
         | Manmohan Mahapatra, Anirban Pal, Kaushik Basu  
         | Indian Institute of Science, India |
| 1390  | Dual Range Forward Topology for High Efficiency at Universal Mains  
         | Noam Ezra, Teng Long  
         | University of Cambridge, United Kingdom |
| 1290  | Automatic Current Balancing Multi-Phase Reconfigurable LLC Converter with Wide Voltage Gain Range for On-Board Battery Charger  
         | Kakeru Koyama, Masatoshi Uno  
         | Ibaraki University, Japan |
| 1594  | A Two-Stage DC–DC Converter with Wide Input Voltage Range Based on Magnetic Isolation Feedback Control  
         | Renxi Dong, Xinbo Ruan, Ye Xu, Jinyang Yu  
         | Nanjing University of Aeronautics and Astronautics, China |
| 2482  | Current Harmonics Dead Time Design Method to Achieve ZVS with Non-Linear Output Capacitance  
         | Matthew Hansen, Abhilash Kamineni, Regan Zane  
         | Utah State University, United States |
| 1944  | Variable Resonant and Switching Frequency Charging Control Strategy of LCC Converter with Wide Range Load  
         | Mengjie Qin, Wenjie Chen, Fan Zhang, Ye Aizhen, Yang Xu, Houran Mohamad Abou  
         | Xi’an Jiaotong University, China |

### Session E14: AC–DC Single Phase Converters – 2

| 1598  | A New Hybrid Si/SiC CCM Totem Pole Bridgeless PFC Design Towards Optimal Performance and Cost Tradeoff  
         | Weibin Chen, Chao Zhang, Kun Qu, Bo Hu, Jing Chen, Jun Wang  
         | Hunan University, China |
|-------|----------------------------------------------------------------------------------------------------------------------------------|
| 2323  | A Single-Stage Four-Phase Totem-Pole AC-DC Converter with Wide Voltage Range and Compact Integrated Magnetic Component  
         | Tat-Thang Le, Ramadhan Muhammad Hakim, Junyeong Park, Sewan Choi  
         | Seoul National University of Science and Technology, Korea |
| 1879  | Paralleled Two-Stage Single-Phase AC-DC Converter Modules Utilizing a Second-Stage Input-Current Based Droop Control Strategy  
         | Danish Shahzad, Khurram K. Afridi  
         | Cornell University, United States |
| 2111  | Modular Hybrid Step-Down PFC Converter for Direct AC/DC Conversion with Differential Power Processing in Data Centers  
         | Ratul Das, Hanh-Phuc Le  
         | University of California San Diego, United States |
1424 | A Bulk-Capacitance Reduction Method Using Self-Driven Thyristor for AC-DC Converters
Niu Jia¹, Han Cui¹, Lingxiao Xue²
¹University of Tennessee Knoxville, United States; ²Oak Ridge National Laboratory, United States

Session E15: AC-DC Single Phase Converters – 3

1095 | A Novel Transformerless Common-Ground AC/DC Switching Converter with Integral Fault Protection utilizing Active Isolation Techniques
Clint Halsted, Madhav Manjrekar, Babak Parkhideh
University of North Carolina Charlotte, United States

1801 | A Discretized Sampling Based Current Sensorless Control of Single-Phase Totem-Pole Power Factor Corrector
Ashwin Chandwani¹, Saikat Dey¹, Ayan Mallik¹, Arun Sankar²
¹Arizona State University, United States; ²Mercedes-Benz R&D North America, Inc., United States

1988 | Design and Implementation of 50V/400A Single-Stage Full-Bridge Synchronous Rectifier for Data Center Application
Isaac Wong¹, Guangqi Zhu², Birger Pahl³, Subhashish Bhattacharya¹
¹North Carolina State University, United States; ²Eaton, United States

2038 | Control Techniques for a Current-Mode-Controlled Merged-Energy-Buffer-Based Two-Stage Electrolytic-Free Offline LED Driver
Maida Farooq¹, Firehiwot Gurara¹, Mausamjeet Khatua¹, Danish Shahzad¹, Saad Pervaiz³, Khurram K. Afridi¹
¹Cornell University, United States; ²Texas Instruments, United States

1862 | Asymmetric Cascaded Transformer Multilevel AC-DC Converter
Bruna S. Gehrke¹, Cursino B. Jacobina¹, Nayara B. de Freitas², Italo R.F.M.P. da Silva³, Reuben P.R. Sousa¹
¹Federal University of Campina Grande, Brazil; ²INESC TEC, Portugal; ³Federal University of Paraíba, Brazil

Session E16: AC-DC MultiPhase Converters – 1

1273 | Implementation of an Isolated Phase-Modular-Designed Three-Phase PFC Rectifier Based on Single-Stage LLC Converter
Mojtaba Forouzesh, Yan-Fei Liu, Paresh C. Sen
Queen’s University, Canada

1644 | Three-Phase PFC Converter with Reconfigurable LCL Filter
Jalal Dadkhah¹, Carl N.M. Ho¹, Ken K.M. Siu², River Tin Ho Li³
¹University of Manitoba, Canada; ²University of North Texas, United States; ³Hong Kong Applied Science and Technology Research Institute Company Limited, Hong Kong

1583 | Isolated Three-Phase AC to DC Converter with Matrix Converter Applying Compensation for Voltage Error by Voltage-Based Commutation
Satoshi Nakamura, Hiroki Watanabe, Shunsuke Takuma, Kashin Kiri, Jun-ichi Itoh
Nagaoka University of Technology, Japan

1843 | Unidirectional Five-Level Rectifiers for WECS Applications
Amanda P. Monteiro¹, Cursino B. Jacobina¹, Filipe A.C. Bahia², Reuben P.R. Sousa¹
¹Federal University of Campina Grande, Brazil; ²Federal University of Bahia, Brazil

1215 | A Three-Phase Voltage Doupler Topology Consisted of Small Number of Switching Devices with Low Switching Frequency
Mizuki Nakahara¹, Hirooki Tokoi¹, Hideto Takada¹, Hironori Oohashi²
¹Hitachi, Ltd., Japan; ²Hitachi Industrial Equipment Systems Co., Ltd., Japan
1873 | Surge Voltage Reduction Method for DAB Matrix Converter Using Circulating Current in Whole Load Condition
Shunsuke Takuma, Kashin Kiri, Hiroki Watanabe, Jun-ichi Itoh
Nagaoka University of Technology, Japan

1976 | Ultra-Light Load Performance Enhancement of a 1 MVA SiC Medium Voltage Three Phase Rectifier
Hanning Tang¹,², Alex Huang¹
¹The University of Texas at Austin, United States; ²SharkNinja Operating LLC, United States

2070 | A Modular Three-Phase Diode Rectifier with High-Frequency Isolation and Sinusoidal Input Currents
Erick I. Pool-Mazun, Jose Sandoval, Prasad Enjeti
Texas A&M University, United States

Session E17: DC–AC Single Phase Converter – 1

2436 | Improved Off-Time Discrete Control for DCM Grid-Tied Inverter with Accurate Average Current Model and considering Nonlinear Parasitic Capacitance
Cheng Huang, Tomoyuki Mannen, Takanori Isobe
University of Tsukuba, Japan

1137 | A High Performance High Frequency Inverter Architecture with Wide Load Range
Chang Liu, Yueshi Guan, Yijie Wang, Dianguo Xu
Harbin Institute of Technology, China

1589 | Design and Analysis of Resonant Inverter for a Wide Range of Input Voltage
Junhyeong Lee, Jung-Ik Ha
Seoul National University, Korea

1065 | A Wide Load Range ZVS Inverter for Radio Frequency Capacitively Coupled Plasma
Si Chen¹, Xinbo Ruan¹, Ying Li²
¹Nanjing University of Aeronautics and Astronautics, China; ²University of Nottingham, United Kingdom

Session E18: DC–AC Single Phase Converter – 2

1954 | Improved Lifetime of GaN-Based Single Phase PV Inverter Using Dynamic Hardware Allocation
Kamal Sabi, Daniel Costinett
The University of Tennessee Knoxville, United States

2137 | Single-Stage Isolated Half-Bridge/Full-Bridge Converter for DC/AC Applications
Laysa L. Souza¹, Diego Acevedo-Bueno¹, Montiê A. Vittorio¹, Edison R.C. da Silva¹, Jens Friebe², Antonio M.N. Lima¹
¹Federal University of Campina Grande, Brazil; ²Leibniz Universität Hannover, Germany

1705 | Multilevel Converter Based on Series and Parallel Connections Using High-Frequency Transformer
Filipe V. Rocha¹, Cursino B. Jacobina¹, Nady Rocha²
¹Federal University of Campina Grande, Brazil; ²Federal University of Paraíba, Brazil

1717 | Multilevel Converter Based on Series and Parallel Connections Using Floating Capacitor
Filipe V. Rocha¹, Cursino B. Jacobina¹, Nady Rocha², Antonio de Paula Dias Queiroz³
¹Federal University of Campina Grande, Brazil; ²Federal University of Paraíba, Brazil; ³Federal Institute of Paraíba, Brazil
1059 | **Accurate Power Loss Model of a Three Level ANPC Inverter Utilizing Hybrid Si/SiC Switching Devices**
Dereje Woldegiorgis, Alan Mantooth
*University of Arkansas, United States*

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**Session E19: AC–AC Isolated**

2512 | **Parallel Capacitive-Link Universal Converters with Low Current Stress and High Efficiency**
Junhao Luo¹, Khalegh Mozaffari², Brad Lehman¹, Mahshid Amirabadi³
¹Northeastern University, United States; ²Enphase Energy, United States

1820 | **PUC Converter Based on AC–DC–AC Multilevel Topologies with a Shared Leg**
Jean T. Cardoso, Cursino B. Jacobina, Phelipe L.S. Rodrigues, Antonio M.N. Lima
*Federal University of Campina Grande, Brazil*

1087 | **Investigation on Operational Range and Suitable Control for Single Phase to Three Phase Matrix Converter**
Tabish Nazir Mir¹, Bhim Singh¹, Abdul Hamid Bhat²
¹Indian Institute of Technology Delhi, India; ²National Institute of Technology Srinagar, India

2103 | **AC-DC-AC Converter with Shared Legs Based on Cascaded Six-Leg and Three-Leg Cells**
Alan S. Felinto, Cursino B. Jacobina
*Federal University of Campina Grande, Brazil*

1457 | **A Single-Phase AC–DC–AC Three-Leg Converter Hybrid with Two and Three Level Legs**
Nustenil S.M.L. Marinus¹, Reuben P.R. Jacobina², Nady Rocha³, Alexandre C. Oliveira⁴, Cursino B. Jacobina⁵, Leonardo C. Pontes¹
¹Federal Institute of Education, Science and Technology of Ceará, Brazil; ²Federal University of Campina Grande, Brazil; ³Federal University of Paraíba, Brazil

1676 | **Three-Phase AC–AC X-Type Indirect Matrix Converters with Open-End Rectifier Stage**
André Wild S. Ramalho, Montiê A. Vitorino, Maurício B.R. Corrêa, Edgar R. Braga-Filho
*Federal University of Campina Grande, Brazil*

2065 | **Novel Comprehensive Control of Matrix Converters**
Galina Mirzaeva, Maria Seron, Graham Goodwin
*The University of Newcastle, Australia*

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**Session E20: Multilevel Converters – Topologies – 1**

2119 | **Modular Isolated Vertically Symmetric Dual Inductor Hybrid Converter for Differential Power Processing**
Ratul Das, Hanh-Phuc Le
*University of California San Diego, United States*

1633 | **Optimized Circulating Current Injection Control Scheme for Modular Multilevel Converters**
Govind Avinash Reddy, Anshuman Shukla
*Indian Institute of Technology Bombay, India*

2105 | **Three-Phase AC-DC-AC Converter with Shared Legs and High-Frequency Link**
Alan S. Felinto, Cursino B. Jacobina
*Federal University of Campina Grande, Brazil*

1145 | **Comprehensive Analysis of the Control Structures for MMC Applications**
Semih Isik, Mohammed Alharbi, Subhashish Bhattacharya
*North Carolina State University, United States*
<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1677</td>
<td>A Single-Phase 35-Levels Cascaded PUC Multilevel Inverter Fed by a Single DC-Source</td>
<td>Samuel C.S. Júnior¹, Cursino Jacobina¹, Edgard L.L. Fabricio²</td>
<td>¹Federal University of Campina Grande, Brazil; ²Federal Institute of Paraíba, Brazil</td>
</tr>
<tr>
<td>2100</td>
<td>A Compact Design Using GaN Semiconductor Devices for a Flying Capacitor Five-Level Inverter</td>
<td>Majid Farhangi¹, Yam P. Siwakoti¹, Reza Barzegarkhoo¹, Saad Ul Hasan¹, Dylan Lu¹, Dan Rogers²</td>
<td>¹University of Technology Sydney, Australia; ²University of Oxford, United Kingdom</td>
</tr>
<tr>
<td>1488</td>
<td>A GaN Based Four-Port Flying Capacitor Multilevel Converter</td>
<td>Mohamed Tamasa Elrais, Issa Batarseh</td>
<td>University of Central Florida, United States</td>
</tr>
<tr>
<td></td>
<td><strong>Session E21: Multilevel Converters – Topologies – 2</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1648</td>
<td>Transformer-Based Single-Phase AC-DC-AC Multilevel Converter for Voltage Step-Up Applications</td>
<td>Rodrigo P. de Lacerda¹, Cursino B. Jacobina¹, Edgard L.L. Fabricio², Jean Torelli Cardoso¹</td>
<td>¹Federal University of Campina Grande, Brazil; ²Federal Institute of Paraíba, Brazil</td>
</tr>
<tr>
<td>1870</td>
<td>A Seven-Level Inverter with Natural Balance and Boosting Capability</td>
<td>Ronnan de B. Cardoso¹, Edison Roberto C. da Silva¹²³, Leonardo R. Limongi¹, André Elias L. da Costa²</td>
<td>¹Federal University of Pernambuco, Brazil; ²Federal University of Campina Grande, Brazil; ³Federal University of Paraíba, Brazil</td>
</tr>
<tr>
<td>1815</td>
<td>Single-Phase AC-DC-AC Multilevel Five-Leg Converter Based on a High-Frequency Transformer</td>
<td>Jean T. Cardoso, Cursino B. Jacobina, Phelipe L.S. Rodrigues, Antonio M.N. Lima</td>
<td>Federal University of Campina Grande, Brazil</td>
</tr>
<tr>
<td>1464</td>
<td>Hybrid Flying Capacitor Inverter Based on Array Bootstrap Driver for High Power Density Application</td>
<td>Jingxiang Shi, Shangzhi Pan, Jinwu Gong, Zhipeng Yin, Xinghua Dang, Minglong Wang</td>
<td>Wuhan University, China</td>
</tr>
<tr>
<td>1263</td>
<td>Performance Assessment of a 13-Levels Self-Balanced Inverter Based on a Dual T-Type Topology</td>
<td>S. Foti¹, A. Testa¹, S. De Caro¹, G. Scelba², A. Cusumano²</td>
<td>¹University of Messina, Italy; ²University of Catania, Italy</td>
</tr>
<tr>
<td>2237</td>
<td>AC-DC Single-Phase Multilevel Converters with Floating DC-Link and Reduced Controlled Switches</td>
<td>Ulisses G. Lima¹, Cursino B. Jacobina², Reuben P.R. Sousa¹, Rodrigo P. de Lacerda¹</td>
<td>Federal University of Campina Grande, Brazil</td>
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</tbody>
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**Session E22: Multilevel Converters – Topologies – 3**

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<tr>
<th>ID</th>
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<tr>
<td>1355</td>
<td>A Single-Phase Five-Level Grid-Connected Inverter for Photovoltaic Applications</td>
<td>Jadyson J. Silva¹, Filipe A.C. Bahia¹, Andre P.N. Tahim¹, Darlan A. Fernandes², Fabiano F. Costa¹</td>
<td>¹Federal University of Bahia, Brazil; ²Federal University of Paraíba, Brazil</td>
</tr>
<tr>
<td>1496</td>
<td>A Three-Level Neutral-Point Clamped Dual-Output Converter</td>
<td>Ahmed S. Hussein, Amer Ghias</td>
<td>Nanyang Technological University, Singapore</td>
</tr>
<tr>
<td>2113</td>
<td>A Novel Seven Level Hybrid Fault Tolerant Converter</td>
<td>Rajat Shahane, Satish Belkhode, Anshuman Shukla</td>
<td>Indian Institute of Technology Bombay, India</td>
</tr>
</tbody>
</table>
1620 | A Six-Switch Five-Level Transformer-Less Inverter without Leakage Current for Grid-Tied PV System
Jaber Fallah Ardashir¹, Mahdi Gasemi¹, Behrouz Rozmeh¹, Saeed Peyghami², Frede Blaabjerg²
¹Islamic Azad University, Iran; ²Aalborg University, Denmark

2097 | A Novel Single-Source Single-Stage Switched-Boost Five-Level (SSB5L) Inverter with Dynamic Voltage Boosting Feature
Majid Farhangi¹, Reza Barzegarkhoo¹, Yam P. Siwakoti¹, Dyan Lu¹, Sze Sing Lee²
¹University of Technology Sydney, Australia; ²Newcastle University in Singapore, Singapore

1334 | A DAB Converter Constructed by Nine-Switch Five-Level Active-Neutral-Point-Clamped Bridges
Na Gao, Yu Zhang, Zengguang Qiu, Qingxin Guan
Huazhong University of Science and Technology, China

1106 | Comparison of an Interleaved Multi-Branch Inverter and a Four-Level Inverter with Variable Voltage Levels for Emulation of Three-Phase Machines
Manuel Fischer, Yang Hu, Johannes Ruthardt, Philipp Ziegler, Jörg Roth-Stielow
University of Stuttgart, Germany

Session E23: Multilevel Converters – Control – 1

1958 | Open-Switch Fault Diagnosis in Four-Level Active Neutral-Point-Clamped Inverters
Jonathan Pribadi, Dong-Choon Lee
Yeungnam University, Korea

1443 | Model-Free Second-Order Sliding Mode Control for Grid-Connected Voltage Source Compact Multilevel Converters
Mohammad Babaie, Kamal Al-Haddad
École de technologie supérieure, Canada

1406 | Self-Balancing 3-Phase 5-Level Flying E-Type Inverter for Photovoltaic Applications
M. di Benedetto¹, A. Lidozzi¹, L. Solero¹, F. Crescimbini¹, P.J. Grbović²
¹Roma Tre University, Italy; ²University of Innsbruck, Austria

1629 | Constant Overlap-Time Based SMs Capacitor Voltage Balancing Scheme for Alternate Arm Converter
Govind Avinash Reddy, Nageswara Rao Karaka, Anshuman Shukla
Indian Institute of Technology Bombay, India

1469 | A Robust Ultra-Local Model Control with DC Capacitor Voltage-Balancing for PEC9 Inverter
Meysam Gheisarnejad¹, Mohammad Sharifzadeh², Mohammad-Hassan Khooban¹, Kamal Al-Haddad²
¹Aarhus University, Denmark; ²École de technologie supérieure, Canada

1467 | Convex Optimization-Based Vector Current Control Design for Grid-Connected Packed E-Cell Inverters
Mahdieh S. Sadabadi¹, Mohammad Sharifzadeh², Majid Mehrasa³, Seddik Bacha³, Kamal Al-Haddad²
¹The University of Sheffield, United Kingdom; ²École de Technologie Supérieure, Canada; ³Université Grenoble Alpes, France

2253 | Hybrid Multilevel T-Type Inverter Exploiting a Nearest Level Modulation Technique
S. Foti¹, A. Testa¹, S. De Caro¹, T. Scimone¹, G. Scelba², G. Scarcella²
¹University of Messina, Italy; ²University of Catania, Italy
### Session E24: Multilevel Converters – Control – 2

<table>
<thead>
<tr>
<th></th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2089</td>
<td>Statcom Operation of Hybrid Series Converter and DC Capacitor Voltage Balance Technique</td>
<td>Ibhan Chand Rath, Anshuman Shukla</td>
<td>Indian Institute of Technology Bombay, India</td>
</tr>
<tr>
<td>1092</td>
<td>Multiplexing the Level Provider of Multilevel Converters in Series-Parallel-Form Switch-Linear Hybrid Envelope Tracking Power Supply</td>
<td>Peng Zhou, Xinbo Ruan, Ning Liu, Yazhou Wang</td>
<td>Nanjing University of Aeronautics and Astronautics, China</td>
</tr>
<tr>
<td>1782</td>
<td>A Novel Inter-Modulated Floating Carrier Level Shifted PWM Method for PUC9 Converter</td>
<td>Kiavash Askari Noghani, Mostafa Abarzadeh, Alireza Javadi, Kamal Al-Haddad</td>
<td>¹École de technologie supérieure, Canada; ²SmartD Technologies Inc., Canada; ³SUEZ Water Technologies &amp; Solutions, Canada</td>
</tr>
<tr>
<td>2009</td>
<td>Splitting of Voltage Reference between Half-Bridge and Full-Bridge Sub-Modules in Hybrid MMC</td>
<td>Risabh Sarangi, Tanmoy Bhattacharya, Dheeman Chatterjee</td>
<td>¹Indian Institute of Technology Kanpur, India; ²Indian Institute of Technology Kharagpur, India</td>
</tr>
<tr>
<td>1462</td>
<td>Circulating Current Control in Arm Link Enhanced Modular Multilevel Converter for Low-Voltage and Variable Frequency Applications</td>
<td>Rodrigo Aguilar, Luca Tarisciotti, Javier Pereda</td>
<td>¹Pontificia Universidad Católica de Chile, Chile; ²Universidad Andrés Bello, Chile</td>
</tr>
<tr>
<td>2088</td>
<td>Common-Mode Voltages Reduction Space Vector Modulation for Active Neutral-Point-Clamped Converter</td>
<td>Jalal Amini, Mehrdad Moallem</td>
<td>Simon Fraser University, Canada</td>
</tr>
<tr>
<td>1284</td>
<td>Analysis and Implementation of a 5-Level Hybrid Inverter with Reduced Switching Devices Using Phase-Shifted PWM</td>
<td>Almachius Kahwa, Hidemine Obara, Yasutaka Fujimoto</td>
<td>Yokohama National University, Japan</td>
</tr>
</tbody>
</table>

### Session E25: DC-AC Multi-Phase Converters – 2

<table>
<thead>
<tr>
<th></th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2148</td>
<td>Overvoltage Mitigation Techniques for SiC-MOSFET Based High-Speed Drives: Comparison of Active Gate Driver and Output dv/dt Filter</td>
<td>Jelena Loncarski, Francesca Maiullari, Rinaldo Consoletti, Vito Giuseppe Monopoli, Francesco Cupertino</td>
<td>¹University of Bologna, Italy; ²Politecnico di Bari, Italy</td>
</tr>
<tr>
<td>2413</td>
<td>Discontinuous Space Vector Pulse Width Modulation for Six Switch Converter with Independent Control of Phase Voltages and Switching Device Stress Alleviation</td>
<td>Josiah O. Haruna, Olorunfemi Ojo</td>
<td>Tennessee Tech University, United States</td>
</tr>
<tr>
<td>1454</td>
<td>Three-Phase Buck-Boost Inverter with Reduced Current Ripple</td>
<td>Ashraf Ali Khan, Usman Ali Khan, Shehab Ahmed</td>
<td>¹King Abdullah University of Science and Technology, Saudi Arabia; ²Yonsei University, Korea</td>
</tr>
<tr>
<td>2238</td>
<td>Optimum Injection of Second Harmonic Circulating Current for Reduction in SubModule Capacitor Voltage Ripple in Overmodulated MMC</td>
<td>G. Veera Bharath, Poras T. Balsara</td>
<td>The University of Texas at Dallas, United States</td>
</tr>
</tbody>
</table>
2581 | **QCM-Enabled SiC Three-Phase Traction Inverter**  
Yanfeng Shen, Yunlei Jiang, Luke Shillaber, Hui Zhao, Teng Long  
*University of Cambridge, United Kingdom*

1335 | **Assessment of a Multi-Functional Converter System for Traction Electric Drives**  
C. Alosa, F. Immovilli, E. Lorenzani  
*University of Modena and Reggio Emilia, Italy*

1756 | **Role of Active Clamp Circuit in a DC/AC Isolated Converter Based on the Principle of Pulsating DC Link**  
Daniele Marciano, Simone Palazzo, Giovanni Busatto, Annunziata Sanseverino, Francesco Velardi  
*University of Cassino and Southern Lazio, Italy*

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**Topic F: Control, Modeling and Optimization of Power Converters**

**Session F01: Dynamic Modeling of Power Converters**

1967 | **An Accurate Dynamic Characteristic Design Method for Boost Converter with PI Control Based on Motion Decomposition and Eigenvalue Configuration**  
Hong Li¹, Zexi Zhou¹, Zhipeng Zhang¹, Guoen Cao², Yajing Zhang³  
¹Beijing Jiaotong University, China; ²Chinese Academy of Science, China; ³Beijing Information Science and Technology University, China

2359 | **Dynamic Phasor Model of Multi-Converter Systems**  
Arash Nazari¹, Yaosuo Xue², Jayesh Kumar Motwani³, Igor Cvetkovic³, Dong Dong³, Dushan Boroyevich¹  
¹Virginia Polytechnic Institute and State University, United States; ²Oak Ridge National Laboratory, United States

1775 | **Frequency Domain Modelling of an LCLC Resonant Converter with Capacitive Output Filter under Hybrid Modulation**  
Shahbaj Dhillon, Abhishek Awasthi, Praveen Jain  
Queen’s University, Canada

1285 | **Reduced-Order Equivalent Circuit Model of Series Resonant Converter considering the Interaction between Resonant Elements**  
Xin Li¹, Shuxin Chen¹, Yi Tang¹, Yiming Zhang², Xin Zhang³  
¹Nanyang Technological University, Singapore; ²Fuzhou University, China; ³Zhejiang University, China

2290 | **Frequency Domain Modelling of an LCC Resonant Converter with Capacitive Output Filter**  
Shahbaj Dhillon, Abhishek Awasthi, Praveen Jain  
Queen’s University, Canada

**Session F02: Reliability, Diagnostics and Fault Analysis of Power Converters**

1686 | **Online Junction Temperature Monitoring of Power Semiconductor Devices Based on a Wheatstone Bridge**  
Niklas Fritz¹, Maximilian Friedel¹, Rik W. De Doncker¹, Timothy A. Polom²  
¹RWTH Aachen University, Germany; ²Silicon Austria Labs GmbH, Austria

2337 | **Junction Temperature Estimation of SiC MOSFETs During Inverter Operation Using Switching Times and On-State Voltages**  
Daniel Herwig, Axel Mertens  
Leibniz Universität Hannover, Germany
Kelvin Yi-wen Hong¹, Henry Shu-hung Chung¹, Alan Wai-Lun Lo², Huai Wang³
¹City University of Hong Kong, China; ²Chu Hai College of Higher Education, China; ³Aalborg University, Denmark

Mode Analysis and Identification Scheme of Open-Circuit Fault in a Three-Phase DAB Converter
Sagar Kumar Rastogi¹, Suyash Sushilkumar Shah¹, Brij N. Singh², Subhashish Bhattacharya¹
¹North Carolina State University, United States; ²John Deere, United States

On-State Voltage Measurement of High-Side Power Transistors in Three-Phase Four-Leg Inverter for In-Situ Prognostics
Chondon Roy, Namwon Kim, James Gafford, Babak Parkhideh
University of North Carolina Charlotte, United States

Current Sharing Control Strategy for Parallel-Connected H-Bridges DC-DC Converter: Modelling, Analysis and HIL Test
Cristina Terlizzi¹, Stefano Bifaretti¹, Alessandro Lampasi²
¹University of Rome “Tor Vergata”, Italy; ²ENEA, DTT S.c.a.r.l., Italy

Improved Instantaneous Flux and Current Control for Three-Phase Dual-Active Bridge DC-DC Converters
Rafael Goldbeck, Jingxin Hu, Rik W. De Doncker
RWTH Aachen University, Germany

A Power Sharing Control Scheme with Fast-Dynamic Response for Input-Series Output-Parallel DAB DC-DC Converter
Nie Hou, Pasan Gunawardena, Xuesong Wu, Li Ding, Yue Zhang, Yun Wei Li
University of Alberta, Canada

A Decentralized Nonlinear Control Scheme for Modular Power Sharing in DC-DC Converters
Soham Roy¹, Mansi Joisher², Alex J. Hanson¹
¹The University of Texas at Austin, United States; ²National Institute of Technology Karnataka, India

Grid-Connected Self-Synchronizing Cascaded H-Bridge Inverters with Autonomous Power Sharing
Soham Dutta¹, Minghui Lu¹, Branko Majmunovic², Rahul Mallik¹, Gab-Su Seo³, Dragi Maksimovic², Brian Johnson¹
¹University of Washington, United States; ²University of Colorado, United States; ³National Renewable Energy Laboratory, United States

Input AC Voltage Sensorless Control Method for Single-Phase PFC Converter Using Frequency Estimator
Seunghoon Baek¹, Chun-Gi Yun², Younghoon Cho³
¹Virginia Polytechnic Institute and State University, United States; ²Korea Electrical Manufacturers Association, Korea; ³Konkuk University, Korea
<table>
<thead>
<tr>
<th>Session F05: Power Converter Stability</th>
</tr>
</thead>
</table>
| **1735** | **An Approach for Modeling and Stability Analysis of Single-Phase Microgrids**  
Nima Amouzegar Ashtiani, S. Ali Khajehoddin, Masoud Karimi-Ghartemani  
1University of Alberta, Canada; 2Mississippi State University, United States  

**1962** | **A Floquet Theory-Based Stability Analysis Method for Cascaded DC-DC Converters by Combining with the Describing Function of PWM Link**  
Hong Li, Zhipeng Zhang, Zexi Zhou, Zhaoyi Chu, Yangbin Zeng, Zhidong Qiu  
Beijing Jiaotong University, China  

**1063** | **Evaluating Small-Signal Synchronization Stability of Grid-Forming Converter through Complex Impedance Plane**  
Jiale Yu, Han Deng, Yi Tang, Yang Qi, Xiong Liu  
1Nanyang Technological University, Singapore; 2Northwestern Polytechnical University, China; 3Jinan University, China  

**1077** | **Stability Analysis and Improvement of Three-Phase Grid-Tied Power Converters through the Generalized Phase Portraits Method**  
Jiale Yu, Yi Tang, Jingyang Fang, Hongchang Li  
1Nanyang Technological University, Singapore; 2Duke University, United States; 3Xinjiang University, China  

---

<table>
<thead>
<tr>
<th>Session F06: Power Converter EMI</th>
</tr>
</thead>
</table>
| **2522** | **Identification and Validation of a Non Symmetrical System Level EMC Model for Power Electronics Converter**  
Blazej Czerniewski, Jean-Luc Schanen, Herve Chazal, Pericle Zanchetta, Caio Fronseca de Freitas  
1Université Grenoble Alpes, France; 2University of Nottingham, United Kingdom; 3University of Pavia, Italy; 4Centrale Lille, France  

**1991** | **PCB Winding Coupled Inductor Design for SiC-Based Soft-Switching Three-Phase C-DC Converter with Balance Technique**  
Gibong Son, Zhengrong Huang, Qiang Li, Fred C. Lee  
Virginia Polytechnic Institute and State University, United States  

**2366** | **Novel Common Mode Voltage Elimination Methods in Three-Phase Four-Wire Grid-Connected Inverters**  
Alexander L. Julian, Giovanna Oriti  
1Consultant, United States; 2Naval Postgraduate School, United States  

**1856** | **Electric Near Field Emission from a 1Mhz Power Converter for Electric Vehicles**  
Yanwen Lai, Juntao Yao, Shuo Wang, Zheng Luo, Yiming Li  
1University of Florida, United States; 2Monolithic Power Systems, Inc., United States  

---

<table>
<thead>
<tr>
<th>Technical Program</th>
</tr>
</thead>
</table>
Session F07: Converter Power Quality

2296 | Parallel Differential Evolution Algorithm Accelerated by Graphics Processing Unit for Harmonic Minimization in Power Converters
Kaiqi Ren, Fei He, Zhaoyuan Li, Kehu Yang
China University of Mining and Technology, China

2473 | Decentralized PWM Interleaving for Ripple Minimization in Both Symmetric and Asymmetric Parallel-Connected DC-DC Converters
Soham Dutta, Minghui Lu, Brian Johnson
University of Washington, United States

1798 | Linear-System-Based Selective Harmonic Elimination Solution for Multilevel Inverters
Concettina Buccella, Maria Gabriella Cimoroni, Carlo Cecati
University of L’Aquila, Italy

1231 | Enhanced Modulation Technique for Power Quality Improvement of LED Drivers
Huan Li¹, Weidong Xiao¹, Sinan Li¹, Jimmy Chih-Hsien Peng²
¹The University of Sydney, Australia; ²National University of Singapore, Singapore

Session F08: Design and Control of Power Converters

2199 | Switching Losses Minimized Harmonic Elimination for Two-Level Inverters
Kehu Yang¹, Suna Pan¹, Huawei Li²
¹China University of Mining and Technology, China; ²Beijing Institute of Aerospace Test Technology, China

1786 | Modeling and ZVS Constraints of the Hybrid-Bridge LLC Resonant Converter for MHz Level Operation
Lingeshwaren Sobrayen¹, Patrick Dehem², Charif Karimi¹, Tanguy Phulpin¹, Daniel Sadarnac¹
¹CentraleSupélec, France, France; ²EnerSys, France

1437 | Splitting Inductance Tuning Method to Eliminate High Frequency Oscillation in Dual Active Bridge Converter
Chang Wang, Jiasheng Huang, Gabriel Zsurzsan, Zhe Zhang
Technical University of Denmark, Denmark

1916 | Minimizing Switching-On Current Spike through GaN in Low Power Applications
Yajie Qiu, Jinseng Vanderkloot, Lucas Lu
GaN Systems, Canada

Session F09: Power Converter Stability and Control

1703 | System-Level Mapping of Modeling Methods for Stability Characterization in Microgrids
Yubo Song¹, Subham Sahoo¹, Yongheng Yang², Frede Blaabjerg¹
¹Aalborg University, Denmark; ²Zhejiang University, China

1674 | A Modular Multilevel Converter as a Grid Emulator in Balanced and Unbalanced Scenarios Using a Delta-Wye Transformer
Ming Jia, Shenghui Cui, Philipp Joebges, Rik W. De Doncker
RWTH Aachen University, Germany

2271 | Transient Performance Evaluation of Grid-Forming Control for Railway Traction Converters considering Inter-Phase Operation
Liang Zhao¹, Zheming Jin², Xiongfei Wang¹
¹Aalborg University, Denmark; ²Beijing Jiaotong University, China
**Technical Program**

**Session F10: Control Aspects of Grid-Connected Converters**

2268 | Valley Current Control for the Flying Capacitor Voltage Balancing in the Three-Level Boost Converter with Variable Switching Frequency
Branislav Stevanović, Pedro Alou, Miroslav Vasić
*Universidad Politécnica de Madrid, Spain*

1634 | A State Trajectory Control Method for Switched-Capacitor-Based Resonant Converter with the Finite State Machine Controller
Pan Wang¹, Rui Ling¹, Dongxue Li²
¹Chongqing University, China; ²Vicor Corporation, United States

**Session F11: Power Converter Control**

2281 | New Predictive Current Control for Modular Multilevel Converters with Revised Prediction Model considering Common-Mode Voltage
Yafei Yin, Zhenbin Zhang, Yuanxiang Sun, Zhen Li
*Shandong University, China*

1880 | Direct Active-Balancing Control of Flying-Capacitor Voltages in an ANPC-Based Multilevel Inverter
Vahid Dargahi¹, Arash Khoshkbar Sadigh²
¹University of Washington, United States; ²The Pennsylvania State University, United States

1956 | Modelling and Controller Design for Three-Phase Four-Leg Three-Level T-Type Inverter
Haoxin Yang, Li Zhang, Pengfei Tu, Yi Tang
*Nanyang Technological University, Singapore*

1989 | Phase Control Using Network Node Voltage Feedback for Capacitor-Coupled Dual Active Bridge DC-DC Converters
Sunghyuk Choi, Jin-Su Hong, Jung-Ik Ha
*Seoul National University, Korea*
2370 | Inverter-Dominated Networked Microgrids with Marine Energy Resources and Energy Storage Systems for Coastal Community Resiliency Enhancement
Yuxi Men¹, Yuhua Du¹, Xiaonan Lu¹, Jianzhe Liu², Feng Qiu²
¹Temple University, United States; ²Argonne National Laboratory, United States

2162 | Shipboard Power Conversion System to Meet MIL-STD-1399 Limits for Pulsed Power Loads
Giovanna Oriti¹, Alexander L. Julian², Daniel P. DeToma³
¹Naval Postgraduate School, United States; ²Consultant, United States; ³US Navy, United States

Session F12: Dynamic Modeling of Power Converters

1997 | Accurate Small-Signal Modeling for Charge-Controlled LLC Resonant Converter
Yi-Hsun Hsieh, Fred C. Lee
Virginia Polytechnic Institute and State University, United States

2405 | An Improved Frequency Domain Based Analytical Model of Voltage-Fed Series LC-Parallel LC Resonant Converter with Capacitive Output Filter
Aiswarya Mathew¹, Abhishek Awasthi¹, Praveen Jain¹, Shahbaj S. Dhillon², Majid Pahlevani¹
¹Queen’s University, Canada; ²Voltsafe Inc., Canada

1027 | A Two-Stage Pulsed Power Supply with Ultra-Fast Dynamic Response and Low Input Current Ripple for Low-Frequency Pulsed Loads
Ye Xu, Xinbo Ruan, Xinze Huang, Jinyang Yu, Hao Zhang
Nanjing University of Aeronautics and Astronautics, China

1860 | Small-Signal Modeling and Output Impedance Analysis of Three Stage Synchronous Generator for More Electric Aircraft
Chengxiang Zhang¹, Shuang Wang¹, Xinbo Ruan¹, Ming Yan², Donghua Wu²
¹Nanjing University of Aeronautics and Astronautics, China; ²Saanex Aero Electric Co. Ltd., China

1601 | A Simplified Time-Domain Gain Model for LLC Resonant Converter
Yuliang Cao, Minh Ngo, Dong Dong, Rolando Burgos
Virginia Polytechnic Institute and State University, United States

Session F13: Modulation of Power Converters

1949 | Discontinuous Modulation of Cascaded H-Bridge StatComs considering Capacitor Voltage Oscillations
Qingxiang Liu¹, Ezequiel Rodriguez¹, Glen G. Farivar¹, Josep Pou¹, Salvador Ceballos², Christopher D. Townsend³, Ramon Leyva⁴
¹Nanyang Technological University, Singapore; ²Basque Research and Technology Alliance, Spain; ³University of Western Australia, Australia; ⁴Universitat Rovira i Virgili, Spain

1209 | Quasi-Reference PWM for 3-Level Voltage Source Inverters
Anatolii Tcai¹, Thiwanka Wijekoon¹, Jun-Hyung Jung², Marco Liserre⁴
¹Huawei Technologies Düsseldorf GmbH, Germany; ²Christian-Albrechts-Universität zu Kiel, Germany

2515 | A Fault Tolerant Modulation Scheme to Eliminate DC Offset and Harmonic Fault Currents in the Balanced Inverter under Switch Short-Circuits Faults
Zhouzhou Wang, Hao Zeng, Thomas M. Jahns, Bulent Sarlioglu
University of Wisconsin Madison, United States

1397 | Common Mode Suppression Method of Current Source Back-to-Back Converter Based on Five-Segment Space Vector Modulation
Kang Liu, Dong Jiang, Zicheng Liu, Ruodong Wang
Huazhong University of Science and Technology, China
1627 | Novel Static Carrier Based Low Frequency Multilevel Modulations with Long Conduction Time: Analysis of Capacitor Voltage Balancing
Corentin Darbas¹, Jean-Christophe Olivier², Nicolas Ginot¹, Frédéric Poitiers¹
¹IETR, France; ²IREENA, France

Session F14: Design and Control of Power Converters I

2062 | A Framework for High Density Converter Electrical-Thermal-Mechanical Co-Design and Co-Optimization for MEA Application
Mustafeez ul Hassan, Zhao Yuan, Asif Imran Emon, Fang Luo
Stony Brook University, United States

2411 | The ZVS Transition Analysis and Optimization for CLLC-Type Resonant DC Transformer
Yuliang Cao, Minh Ngo, Dong Dong, Rolando Burgos
Virginia Polytechnic Institute and State University, United States

1915 | Harmonic Compensation Control of Grid Interactive Inverters Based on Data-Driven Harmonic State Space Modeling
Dongsen Sun, Shengyi Wang, Liang Du, Xiaonan Lu
Temple University, United States

1309 | Preliminary Testing and Implementation of a Peak Current Mode Control Scheme for a Two-Phase, Dual Interleaved Buck-Boost Converter
Kevin Cano-Pulido, Ismael Araujo-Vargas, Nancy Mondragón-Escamilla, Enrique Velázquez-Elizondo
Instituto Politécnico Nacional, Mexico

Session F15: Utility Applications of Power Electronics

1208 | DC Fault Current Estimation in a Multi-Terminal Hybrid MMC-HVDC System considering Fault Ride through Control
Yi Xu¹, Liang Qin¹, Yi Zhang², Kaipei Liu¹, Frede Blaabjerg²
¹Wuhan University, China; ²Aalborg University, Denmark

2341 | Power Device Losses in Two-Level Converters with Direct Current Controllers for Grid Connected Applications
Jose Ortiz Gonzalez¹, Diego Pérez-Estévez², Ruizhu Wu¹, Jesús Doval-Gandoy², Phil Mawby¹,
Olayiwola Alatise¹
¹University of Warwick, United Kingdom; ²University of Vigo, Spain

Zerui Dong¹, Suman Debnath², Wei Li³, Qianxue Xia⁴, Phani R.V. Marthi³, Sudipta Chakraborty¹
¹OPAL-RT Corporation, United States; ²Oak Ridge National Laboratory, United States; ³OPAL-RT Technologies, Inc., Canada; ⁴Georgia Institute of Technology, United States

1109 | Design and Analysis of a High-Efficiency All-SiC Dynamic Voltage Restorer for Wide-Range Sag/Swell Mitigation
Lorenzo Ceccarelli, Xinwei Xu, Gabriel Tibola, Jorge L. Duarte
Eindhoven University of Technology, The Netherlands

1818 | Transformer-Less Alternative Topologies of a Unified Power Quality Conditioner with Embedded Hybrid Energy Storage
Jose M. Piedra¹, Pablo García², Ramy Georgious¹, Geber Villa², Mhret Berhe Gebremariam²
¹ENFASYS, Spain; ²University of Oviedo, Spain
Session F16: Other Topics in Design, Control, Modelling and Optimization of Power Converters

1606 | A Remote Development Process and Platform for Power Electronic Systems
Michael Starke, Bailu Xiao, Mitch Smith, Pankaj Bhowmik, Steven Campbell, Radha K. Moorthy, Benjamin Dean, Madhu Chinthavali
Oak Ridge National Laboratory, United States

1920 | An Improved Low Speed Control Strategy for Permanent Magnet Synchronous Motor with Low Resolution Encoder
Qiushi Zhang, Yin Fan
Southeast University, China

2448 | A Novel Trapezoidal Slope Compensation Technique with Peak Current Mode Control for Power Converters Switching at MHz Frequencies
Gnana Sambandam K.1, Yu Yao1, Harish S. Krishnamoorthy1, Harshit Soni2, Amitava Das2
1University of Houston, United States; 2Tagore Technology, United States

1753 | Performance Analysis of an Input-Series-Output-Parallel LLC Resonant Converter with Parameters Mismatch
Qingxuan Ma, Qingyun Huang, Alex Q. Huang
The University of Texas at Austin, United States

1179 | DC-Link Inductor Investigation for Series-Connected Current Source Converter
Zijian Wang, Bowen Jiang, Qiang Wei
Lakehead University, Canada

1499 | Toroidal Inductor Design and Comparison between Interleaved and Non-Interleaved 300 kW High Efficiency SiC Inverter
Harish Suryanarayana1, Maziar Mobarez1, Jacob Miscio1, Xiaqing Song1, Arun Kadavelugu1, Silvio Colombi2
1ABB, United States; 2ABB, Switzerland

2481 | Minimization of DC-Link Capacitance for a DC-Link Based Variable Speed Constant Frequency Aircraft Power System
Goutham Selvaraj1, Kaushik Rajashekar1, Krishna Raj Ramachandran Potti2
1University of Houston, United States; 2Indian Institute of Technology Delhi, India

Session F17: Power Converter Modeling and Control – 1

1130 | A Simple Common-Mode Voltage Reduction Method Based on Zero-Sequence Voltage Injection for a Back-to-Back Three-Level NPC Converter
Xiaona Xu, Kui Wang, Zedong Zheng, Yongdong Li
Tsinghua University, China

1157 | Design and Implementation of Bidirectional Voltage-Multiplier Front-End Converter for Switched Reluctance Motor Drive
Hung-Chi Chen, Yu-Jen Lin
National Yang Ming Chiao Tung University, Taiwan

2355 | Efficient Predictive Control Scheme for Optimal Operation of Five Level Four Switch Inverter
Zhanfan Yu, Sally Sajadian
Lafayette College, United States
<table>
<thead>
<tr>
<th>Session F18: Power Converter Modeling and Control – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1128</strong></td>
</tr>
<tr>
<td>Hamid Naseem, Jul-Ki Seok</td>
</tr>
<tr>
<td>Yeungnam University, Korea</td>
</tr>
<tr>
<td><strong>1630</strong></td>
</tr>
<tr>
<td>Luca Tarisciotti¹, Luca Papini², Constanza Ahumada³, Paolo Bolognesi²</td>
</tr>
<tr>
<td>¹University Andres Bello, Chile; ²University of Pisa, Italy; ³University of Chile, Chile</td>
</tr>
<tr>
<td><strong>1946</strong></td>
</tr>
<tr>
<td>Gyu Cheol Lim, Gwangyol Noh, Jung-Ik Ha</td>
</tr>
<tr>
<td>Seoul National Univeristy, Korea</td>
</tr>
<tr>
<td><strong>1723</strong></td>
</tr>
<tr>
<td>Federico Cecati¹, Marco Liserre¹, Yicheng Liao², Xiongfei Wang², Frede Blaabjerg²</td>
</tr>
<tr>
<td>¹Christian-Albrechts-Universität zu Kiel, Germany; ²Aalborg University, Denmark</td>
</tr>
<tr>
<td><strong>2379</strong></td>
</tr>
<tr>
<td>Daniele Marciano, Simone Palazzo, Carmine Abbate, Giovanni Busatto, Annunziata Sanseverino, Davide Tedesco, Francesco Velardi</td>
</tr>
<tr>
<td>University of Cassino and Southern Lazio, Italy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Session F19: Power Converter Modeling and Control – 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1266</strong></td>
</tr>
<tr>
<td>Marco Torrisi¹, Sebastiano Messina¹, Mario Cacciato²</td>
</tr>
<tr>
<td>¹STMicroelectronics, Italy; ²University of Catania, Italy</td>
</tr>
<tr>
<td><strong>1036</strong></td>
</tr>
<tr>
<td>Thibaut Harzig, Brandon Grainger</td>
</tr>
<tr>
<td>University of Pittsburgh, United States</td>
</tr>
<tr>
<td><strong>1912</strong></td>
</tr>
<tr>
<td>Mahima Gupta</td>
</tr>
<tr>
<td>Portland State University, United States</td>
</tr>
<tr>
<td><strong>2404</strong></td>
</tr>
<tr>
<td>Minghui Lu¹, Rahul Mallik¹, Brian Johnson¹, Sairaj Dhople²</td>
</tr>
<tr>
<td>¹University of Washington, United States; ²University of Minnesota, United States</td>
</tr>
<tr>
<td>Session F20: Power Converter Modeling and Control – 4</td>
</tr>
<tr>
<td>---</td>
</tr>
</tbody>
</table>
| **2304** | Small Signal Stability Analysis of Paralleled Grid-Forming Islanded Voltage Regulated Inverters Using Self Synchronization  
Peishuo Mu, Brendan McGrath, Donald Grahame Holmes, Carlos Teixeira  
RMIT University, Australia |
| **1780** | A Carrier-Based PWM to Achieve Minimum Flux of Coupled Inductor for Interleaved Three-Level Inverters  
Ruirui Chen¹, Fred Wang¹²  
¹The University of Tennessee Knoxville, United States; ²Oak Ridge National Laboratory, United States |
| **2305** | Discrete Time Analysis of Dual Loop Stationary Frame Integral Dominant Voltage Regulated Inverters  
Haris Siraj, Brendan McGrath, Inam Ullah Nutkani  
RMIT University, Australia |
| **1289** | Deep Reinforcement Learning Based Input Voltage Sharing Method for Input-Series Output-Parallel Dual Active Bridge Converter in DC Microgrids  
Yu Zeng¹, Ali Maswood¹, Josep Pou¹, Xin Zhang³, Changjiang Sun¹, Zhan Li¹, Suvajit Mukherjee², Amit Kumar Gupta³, Jiaxin Dong¹  
¹Nanyang Technology University, Singapore; ²Zhejiang University, China; ³Rolls-Royce@NTU Corporate Lab, Singapore |
| **1343** | An LLC-Resonant Power Decoupling Strategy for a Quad-Active-Bridge Power Channel Based AC/DC Power Electronics Transformer  
Xiaohui Li¹, Linqian Cheng¹, Liqun He¹, Chudi Lin¹, Cheng Wang², Zhongkui Zhu¹  
¹Soochow University, China; ²Nanjing University of Science and Technology, China |
| **1595** | Zero-Sequence Circulating Current Suppression with Stand-Alone Feedforward Control for Power Hardware-in-the-Loop System  
Jun-Hyung Jung, Marius Langwasser, Sante Pugliese, Marco Liserre  
Christian-Albrechts-Universität zu Kiel, Germany |
| **1353** | Variable Frequency Repetitive-Resonant Combined Control for Grid-Tied and Intentional Islanding Operations  
Marco di Benedetto, Alessandro Faro, Luca Bigarelli, Alessandro Lidozzi, Luca Solero  
Roma Tre University, C-PED, Italy |

**Session F21: Power Converter Stability I**

| **2563** | Improved Bilinear Discrete-Time Modeling of the Single-Phase Dual Active Bridge DC-DC Converter  
Mohammad Tauquir Iqbal, Ali Iftekhar Maswood, Md Shafquat Ullah Khan, Yu Zeng  
Nanyang Technological University, Singapore |
| **1596** | Interaction Analysis of Current Control Loops in MMC under Asymmetrical Grid Faults  
Jianglong Che, Meng Huang, Xiaoming Zha, Ju Sheng, Xikun Fu  
Wuhan University, China |
| **1184** | Transient Angle Stability Prediction of Virtual Synchronous Generator Using LSTM Neural Network  
Yang Shen, Zhikang Shuai, Chao Shen, Xia Shen, Jun Ge  
Hunan University, China |
1155 | Modeling and Rekasius Substitution Stability Analysis of the Multi-Terminal MMC-HVDC Cyber-Physical System
Jingming Cao¹, Chaoyu Dong¹,², Xiaodan Yu¹, Yunfei Mu¹, Qian Xiao¹, Hongjie Jia¹
¹Tianjin University, China; ²Imperial College London, United Kingdom

1275 | Region-Based Stability Analysis on DC MGs with Consensus-Based Secondary Control and Communication Delay
Yuhua Du¹, Yuxi Men¹, Lizhi Ding¹, Xiaonan Lu², Bo Chen², Jianzhe Liu²
¹Temple University, United States; ²Argonne National Laboratory, United States

Session F22: Control Aspects in Power Electronic Systems – 1

2216 | Distributed Control for Modular Multilevel Converters Operated in Switching-Cycle Balancing Mode
Boran Fan¹, Jun Wang², Yu Rong¹, Vladimir Mitrovic¹, Jianghui Yu¹, Slavko Mocevic¹, Rolando Burgos¹, Dushan Boroyevich¹
¹Virginia Polytechnic Institute and State University, United States; ²University of Nebraska Lincoln, United States

1523 | Decoupled Modulation Scheme for Three-Phase Four-Leg Four-Wire Three-Level T-Type Inverter
Li Zhang, Haoxin Yang, Pengfei Tu, Yi Tang
Nanyang Technological University, Singapore

1631 | Second-Order Sliding-Mode Controller for Boost Converters with Parameter Estimation
Celiang Deng¹, Rui Ling¹, Dongxue Li²
¹Chongqing University, China; ²Vicor Corporation, United States

2369 | Adaptive Pre-Synchronization and Discrete-Time Implementation for Unified Virtual Oscillator Control
M.A. Awal, Md Rifat Kaisar Rachi, Md Rashed Hassan Bipo, Hui Yu, Iqbal Husain
North Carolina State University, United States

2502 | An Improved Model-Free Finite Control Set Predictive Power Control for PWM Rectifiers
Haitao Yang¹, Zeyu Min¹, Yongchang Zhang¹, Zeting Wang¹, Dong Jiang²
¹North China University of Technology, China; ²Huazhong University of Science and Technology, China

1345 | Feed-Forward Compensation for Model Predictive Control in Tri-Port Current-Source Medium-Voltage String Inverters for PV-Plus-Storage Farms
Zheng An, Rajendra Prasad Kandula, Deepak Divan
Georgia Institute of Technology, United States

Session F23: Control Aspects in Power Electronic Systems – 2

1884 | A Control Method Based on Power Factor for Improving Output Voltage Stability and Efficiency of LLC Converter in Wide Range of Output Voltage and Load Impedance
Kazuhiro Umetani¹, Kota Shimomura¹, Kenta Yamada¹, Taichi Kawakami², Ishihara Masataka¹, Eiji Hiraki¹
¹Okayama University, Japan; ²Osaka Prefecture University College of Technology, Japan

1110 | An Unequal Power Sharing Strategy for Capacitive- and Inductive-Coupling Inverters in Microgrid
Wenyang Deng, Qinhao Li, Yongjun Zhang, Yingqi Yi, Guoquan Huang
South China University of Technology, China

2525 | PWM Control of 3-Phase PFC Vienna Rectifier Derived from an Average Current-Based Control of Single-Phase PFC Boost Converter
Lotfi Beghou, Miteshkuma Popat, Steven MacDonald
Leonardo DRS, Canada
Technical Program

2392 | Computation-Cost-Invariant Universal Space-Vector Pulse-Width Modulation for Multilevel Inverters
Fa Chen, Wei Qiao, Hongmei Wang, Liyan Qu
University of Nebraska Lincoln, United States

1640 | Unified Cost Function Model Predictive Control for a Three-Stage Smart Transformer
Luca Tarisciotti¹, Giampaolo Buticchi², Giovanni De Carne³, Yang Jiajun², Chunyang Gu², Patrick Wheeler⁴
¹University Andres Bello, Chile; ²University of Nottingham Ningbo, China; ³Karlsruhe Institute of Technology, Germany; ⁴University of Nottingham, United Kingdom

Session F24: Control Aspects in Power Electronic Systems – 3

2339 | Oversampling Multi-Variable Control for Soft-Switching Solid-State Transformer
Decheng Yan, Aniruddh Marellapudi, Rajendra Prasad Kandula, Deepak Divan
Georgia Institute of Technology, United States

1068 | Complete Time-Delay Compensation Method for LCL-Type Grid-Connected Inverter with Capacitor-Current Active Damping
Shaojie Li, Hua Lin, Xingwei Wang, Ting Hua
Huazhong University of Science and Technology, China

2054 | Noise Mitigation in Control Effort in Three-Phase DC-AC Converters Using LQG/LTR Tracker
Jesus D. Vasquez-Plaza, Juan F. Patarroyo-Montenegro, Andres F. Lopez-Chavaro, Enrique A. Sanabria-Torres, Daniel D. Campo-Ossa, Fabio Andrade
University of Puerto Rico, Puerto Rico

1504 | Output Current Limiting for ON-OFF Controlled Very High Frequency Class E DC-DC Converter
Ying Li, Xinbo Ruan, Si Chen
Nanjing University of Aeronautics and Astronautics, China

1043 | A Constant Current Digital Control Method for Primary-Side Regulation Active-Clamp Flyback Converter in CCM Mode
Chong Wang¹, Daying Sun¹, Xiang Zhang¹, Wenhua Gu¹, Sang Gui²
¹Nanjing University of Science and Technology, China; ²Wuxi Taclink Optoelectronics Technology Company Limited, China

1800 | A Comparison between Single-Stage and Dual-Stage High-Gain GaN DC/DC Converters for Li-ion Battery Modules
Miguel Crespo¹, Pablo García², Konstantin Edl³, Ramy Georgious⁴, Cristian Blanco³, Igor Cantero¹
¹Cegasa, Spain; ²University of Oviedo, Spain; ³IsarAerospace Technologies GmbH, Germany; ⁴ENFASYS, Spain

Session F25: Modeling and Control in Power Electronic Systems

1811 | Data-Driven Modeling of Power-Electronics-Based Power Systems considering the Operating Points Variation
Mengfan Zhang¹, Xiongfei Wang¹, Qianwen Xu²
¹Aalborg University, Denmark; ²KTH Royal Institute of Technology, Sweden

1858 | Modeling and Impedance Analysis of a Turbine-Generator-Rectifier System with Electromechanical Dynamic Interactions in More Electric Aircraft
Qing Lin¹, Bo Wen¹, Rolando Burgos¹, John Noon²
¹Virginia Polytechnic Institute and State University, United States; ²Moog Inc., United States

2265 | Comparison of Anti-Windup Alternatives for Parallel Controllers
Cristina González Moral¹, Diego Fernández Laborda², Juan M. Guerrero Muñoz², Carlos Rivas¹, David Diaz Reigosa²
¹Electrotécnica Industrial y Naval S.L., Spain; ²University of Oviedo, Spain
Adaptive Voltage Positioning Design of Single Stage 48/1V Sigma Converter for Fast Transient Response
Xin Lou¹, Qiang Li¹, Mohamed H. Ahmed²
¹Virginia Polytechnic Institute and State University, United States; ²Texas Instruments, United States

Common Mode EMI Analysis in Power Electronics Enabled Power System
Ashik Amin, Tahmid Ibne Mannan, Seungdeog Choi
Mississippi State University, United States

A Fully Integrated CM Choke with Improved DM Noise Attenuation
Shiqi Jiang, Panbao Wang, Wei Wang, Wei Wei, Guihua Liu, Dianguo Xu
Harbin Institute of Technology, China

Switching Transient Traced Scheme Based on Sinusoidal Waveform to Reduce EMI for IGBTs
Jianan Chen, Dong Jiang, Wei Sun
Huazhong University of Science and Technology, China

Planar Common-Mode EMI Filter Design and Optimization in a 100-kW SiC-Based Generator-Rectifier System for High-Altitude Operation
Xingchen Zhao, Jiewen Hu, Lakshmi Ravi, Dong Dong, Rolando Burgos
Virginia Polytechnic Institute and State University, United States

Quantitative Analysis of Third-Harmonic Neutral-Point Current, Its Impacts, and Mitigation in Three-Level NPC Inverters
D. Venkatramanan¹, V. Nimesh², Brian Johnson², Sairaj Dhople¹
¹University of Minnesota, United States; ²University of Washington, United States

Evaluation of Objective Functions Used in Bio-Inspired Harmonic Optimization Algorithms for Multilevel Converters
Kaiqi Ren, Zhaoyuan Li, Kehu Yang
China University of Mining and Technology, China

Four-Wire Active Power Filter Based on Asymmetric Cascaded H-Bridges
Samuel C.S. Júnior¹, Cursino Jacobina¹, Edgard L.L. Fabricio²
¹Federal University of Campina Grande, Brazil; ²Federal Institute of Paraíba, Brazil

Improved LCL Filter Design Procedure for Grid-Connected Voltage-Source Inverter System
Xingyu Yang, Mohammad Alathamneh, R.M. Nelms
Auburn University, United States

A Family of Redundant-Switch Configurations for Improving Fault-Tolerant Feature of Power Converters
Tohid Rahimi¹, Hossein Khoun Jahan², Saeed Peyghami³, Ding Lei¹, Frede Blaabjerg³, Pooya Davari³
¹Shandong University, China; ²Azarbaijan Regional Electric Company, Iran; ³Aalborg University, Denmark

Performance Evaluation of the Multiwinding Redundancy Approach in MTB DC-DC Converters
Thiago Pereira, Felix Hoffmann, Marco Liserre
Christian-Albrechts-Universität zu Kiel, Germany
Session F29: Reliability, Diagnostics and Fault Analysis of Power Converters – 2

1767 | Employing the Generative Adversarial Networks (GAN) for Reliability Assessment of Converters
Amirali Davoodi¹, Saeed Peyghami¹, Yongheng Yang¹, Tomislav Dragičević³, Frede Blaabjerg¹
¹Aalborg University, Denmark; ²Zhejiang University, China; ³Technical University of Denmark, Denmark

1298 | Reliability of Wind Turbine Power Modules Using High-Resolution Wind Data Reconstruction: A Digital Twin Concept
Nikolaos Iosifidis¹, Yanghao Zhong¹, Borong Hu², Biyun Chen³, Li Ran¹, Subhash Lakshminarayana¹,
Chunjian Jia², Paul McKeever³, Chong Ng³
¹University of Warwick, United Kingdom; ²University of Cambridge, United Kingdom; ³Guangxi University, China; ⁴Offshore Renewable Energy Catapult, United Kingdom

1511 | A Comparative Study on Converter-Level On-State Voltage Measurement Circuits for Power Semiconductor Devices
Yingzhou Peng, Huai Wang
Aalborg University, Denmark

1384 | An Ultra-Fast Short Circuit Protection for Three-Phase GaN Electric Drives
Darian Verdy Retianza, Luc Spooren, Jeroen van Duivenbode, Henk Huisman
Eindhoven University of Technology, The Netherlands

1788 | An Application of Feature Engineering and Machine Learning Algorithms on Condition Monitoring of SiC Converters
Afshin Loghmani Moghaddam Toussi, Amir Sajjad Bahman, Francesco Iannuzzo, Frede Blaabjerg
Aalborg University, Denmark

Topic G: Electrical Machines

Session G01: Electric Machines in Transportation

1766 | Experimental Investigation of a Slotless Skewed Stator with a Composite Winding Layer
Suzanne Collins, Philip Mellor, Nick Simpson
University of Bristol, United Kingdom

1577 | Optimization of an IPM Traction Motor considering the Electric Drive Unit System Requirements
Jonathan Godbehere, Mircea Popescu, Melanie Michon
Motor Design Ltd., United Kingdom

2001 | Comparison of Candidate Designs and Performance Optimization for an Electric Traction Motor Targeting 50 kW/L Power Density
Nanjun Tang, Ian P. Brown
Illinois Institute of Technology, United States

2402 | A Comprehensive Comparison of Concentrated Winding and Distributed Continuous Winding Machine Topologies for Hybrid Electric Vehicles
Tausif Husain, Cong Ma, Narges Taran, Zhao Wan
BorgWarner Inc., United States
<table>
<thead>
<tr>
<th>Session G02: Permanent Magnet Machines – 1</th>
</tr>
</thead>
</table>
| **1625** | **Effect of the Interaction of Different Manufacturing Imperfections on the Unbalanced Radial Forces in a Sub-Fractional HP Single-Phase BLDC Motor**  
Nejat Saed, Stefan Leitner, Annette Mütze  
Graz University of Technology, Austria |
| **2565** | **Determination of the Symmetric Short-Circuit Currents of Synchronous Permanent Magnet Machines Using Magnetostatic Flux Maps**  
Simone Ferrari, Paolo Ragazzo, Gaetano Dilevrano, Gianmario Pellegrino  
Politecnico di Torino, Italy |
| **1320** | **Cogging Torque Analysis in a Series Hybrid Variable Flux Machine Using Lumped Magnetic Circuits**  
Dwaipayan Barman, Pragasen Pillay  
Concordia University, Canada |
| **2142** | **A Generalized Theory to Predict the Torque Harmonics in Permanent Magnet Machines**  
Anant K. Singh¹, Ramakrishnan Raja¹, Tomy Sebastian¹, Kaushik Rajashekara²  
¹Halla Mechatronics, United States; ²University of Houston, United States |

<table>
<thead>
<tr>
<th>Session G03: Modeling of Electric Machines – 1</th>
</tr>
</thead>
</table>
| **2363** | **The DQ-Theta Flux Map Model of Synchronous Machines**  
Simone Ferrari, Gaetano Dilevrano, Paolo Ragazzo, Gianmario Pellegrino  
Politecnico di Torino, Italy |
| **2272** | **Fast Flux Mapping of PM and Synchronous Reluctance Machines: Method Description and Comparison with Full FEA Approach**  
Matteo Carbonieri¹, Wen L. Soong², Amin Mahmoudi³, Nicola Bianchi¹  
¹University of Padova, Italy; ²University of Adelaide, Australia; ³Flinders University, Australia |
| **1165** | **Optimization of a Line-Start Motor for Centrifugal Loads within Premium Efficiency According to IEC Standard**  
Diego Troncon¹, Luigi Alberti¹, Leone Donazza², Mauro Daneluzzi², Massimo Trova²  
¹University of Padova, Italy; ²Orange1 Spa, Italy |
| **1947** | **Optimum Design Study on HEFSM Using Variably Magnetizable PM with Low L/D Ratio and Novel PM Arrangement for EV/HEV Traction Applications**  
Takeshi Okada, Mitsuru Saito, Takashi Kosaka, Hiroaki Matsumori, Nobuyuki Matsumi  
Nagoya Institute of Technology, Japan |

<table>
<thead>
<tr>
<th>Session G04: Permanent Magnet Machines – 2</th>
</tr>
</thead>
</table>
| **1411** | **Recent Advances in Analysis and Design of Axial Flux Permanent Magnet Electric Machines**  
F.N.U. Nishanthi¹, Joachim Van Verdegem², Eric L. Severson¹  
¹University of Wisconsin Madison, United States; ²Université catholique de Louvain, Belgium |
| **2085** | **Investigation of Asymmetric Axial-Flux Hybrid Excited Electrodynamic Wheels for Maglev Transportation**  
Wei Qin¹, Ma Yuhua², Lv Gang¹, Wang Fuyao¹, Song Chengrui¹, Zhang Jielong¹  
¹Beijing Jiaotong University, China; ²Taiyuan Institute of China Coal Technology and Engineering Group, China |
| **2372** | **A Survey on the Design and Analysis of Magnetic Screws**  
Doha Mostafa, Hussain A. Hussain  
Kuwait University, Kuwait |
### Session G05: Electric Machines: Fault Analysis

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
</table>
| 2275         | Impact of Static and Dynamic Eccentricity on the Performance of Permanent Magnet Synchronous Machines with Modular Stator Core | Danilo Riquelme, Werner Jara, Carlos Madariaga, Juan Tapia, Gerd Bramerdorfer, Javier Riedemann.  
1Pontificia Universidad Católica de Valparaíso, Chile; 2University of Concepcion, Chile; 3Johannes Kepler University Linz, Austria; 4The University of Sheffield, United Kingdom |
| 2463         | Performance of Dual Wound Synchronous Reluctance Machines for High Performance Applications considering Winding Faults    | Mazharul Chowdhury, Mohammad Islam, Iqbal Husain.  
1North Carolina State University, United States; 2Halla Mechatronics, United States |

### Session G06: Thermal Analysis of Electric Machines

<table>
<thead>
<tr>
<th>Paper Number</th>
<th>Title</th>
<th>Authors</th>
</tr>
</thead>
</table>
| 1564         | Model Calibration of Oil Jet and Oil Spray Cooling in Electrical Machines with Hairpin Windings | Chuan Liu, Yew Chuan Chong, Melanie Michon, James Goss, David Gerada, Zeyuan Xu, Chris Gerada, He Zhang.  
1University of Nottingham, United Kingdom; 2Motor Design Ltd., United Kingdom; 3University of Nottingham Ningbo, China |
| 2464         | Approaches for Improving Lumped Parameter Thermal Networks for Outer Rotor SPM Machines | Daniel Wöckinger, Gerd Bramerdorfer, Silvio Vaschetto, Andrea Cavagnino, Alberto Tenconi, Wolfgang Amrhein, Frank Jeske.  
1Johannes Kepler University Linz, Austria; 2Politecnico di Torino, Italy; 3ebm-papst St. Georgen GmbH & Co. KG, Germany |
| 2182         | Electromagnetic and Thermal Evaluation of Surface-Mounted PM Vernier Machines | Mostafa Ahmadi Darmani, Silvio Vaschetto, Andrea Cavagnino, Mircea Popescu.  
1Politecnico di Torino, Italy; 2Motor Design Ltd., United Kingdom |
1Politecnico di Torino, Italy; 2Baylor University, United States |
### Session G07: Electric Machines Materials and Additive Manufacturing

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1771</td>
<td>Additive Manufacturing of a Conformal Hybrid-Strand Concentrated Winding Topology for Minimal AC Loss in Electrical Machines</td>
<td>Nick Simpson¹, Jakob Jung², Axel Helm², Phil Mellor¹</td>
<td>¹University of Bristol, United Kingdom; ²Additive Drives GmbH, Germany</td>
</tr>
<tr>
<td>1934</td>
<td>Multi-Permeability Optimization Approach for the Iron Core of a Synchronous Reluctance Machine – an Application of Additive Manufacturing</td>
<td>Thang Q. Pham, Shanelle N. Foster</td>
<td>Michigan State University, United States</td>
</tr>
<tr>
<td>1650</td>
<td>Selection of Soft Magnetic Composite Material for Electrical Machines Using 3D FEA Simulations</td>
<td>Maged Ibrahim¹, Sumeet Singh², Dwaipayan Barman², Fabrice Bernier¹, Jean-Michel Lamarre¹, Serge Grenier³, Pragasen Pillay²</td>
<td>¹National Research Council of Canada, Canada; ²Concordia University, Canada; ³Rio Tinto Fer et Titane, Canada</td>
</tr>
<tr>
<td>1722</td>
<td>Flux Switching Permanent Magnet Motor with Metal Amorphous Nanocomposite Soft Magnetic Material and Rare Earth Free Permanent Magnets</td>
<td>Satoru Simizu¹, Kevin Byerly¹, Kyle Schneider¹, Heonyoung Kim², Mark Nations², Sneha Narasimhan², Richard Beddingfield³, Subhashish Bhattacharya², Michael E. McHenry¹</td>
<td>¹Carnegie Mellon University, United States; ²North Carolina State University, United States</td>
</tr>
</tbody>
</table>

### Session G08: Loss Analysis in Electric Machines

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1048</td>
<td>Experimental Determination of Conductor Lay and Impact on AC Loss in Volume Manufactured Machines Using X-Ray Computed Tomography</td>
<td>Joshua Hoole¹, Nick Simpson¹, Philip H. Mellor¹, Abdeljalil Daanoune²</td>
<td>¹University of Bristol, United Kingdom; ²hofer powertrain UK Ltd., United Kingdom</td>
</tr>
<tr>
<td>1645</td>
<td>Loss Mitigation Techniques for a Novel Toroidal Permanent Magnet Motor</td>
<td>Maged Ibrahim, Fabrice Bernier, Jean-Michel Lamarre</td>
<td>National Research Council of Canada, Canada</td>
</tr>
<tr>
<td>1708</td>
<td>Computationally Efficient Prediction of Statistical Variance in the AC Losses of Multi-Stranded Windings</td>
<td>Philip Mellor, Joshua Hoole, Nick Simpson</td>
<td>University of Bristol, United Kingdom</td>
</tr>
<tr>
<td>1802</td>
<td>Experimental Evaluation of Iron Losses in Radial Flux Permanent Magnet Synchronous Machines</td>
<td>Gereon Goldbeck, Gerd Bramerdorfer, Daniel Wöckinger, Christoph Dobler, Wolfgang Amrhein</td>
<td>Johannes Kepler University Linz, Austria</td>
</tr>
</tbody>
</table>

### Session G09: Noise and Vibrations in Electric Machines

<table>
<thead>
<tr>
<th>ID</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1809</td>
<td>Effects of Stator Laminations on Acoustic Noise of Electrical Machines</td>
<td>Issah Ibrahim, David Alister Lowther</td>
<td>McGill University, Canada</td>
</tr>
<tr>
<td>1673</td>
<td>Analysis of Claw Deflections and Radial Magnetic Forces in Low-Cost Sub-Fractional Horsepower BLDC Claw-Pole Motors</td>
<td>Stefan Leitner, Nejat Saed, Annette Mütze</td>
<td>Graz University of Technology, Austria</td>
</tr>
</tbody>
</table>
2319 | Dominant Spatial Order Airgap Force Based Current Profiling Coupled with Fast Vibration Prediction in Switched Reluctance Machines for NVH Mitigation
Shuvajit Das¹, Md Ehsanul Haque¹, Anik Chowdhury¹, Yilmaz Sozer¹, David Colavincenzo², Fernando Venegas³, Jeffrey Geither³
¹The University of Akron, United States; ²Bendix Commercial Vehicle Systems, United States

2358 | Direct Acceleration Harmonic Control with Current Harmonics Injection Method to Reduce Acoustic Noise and Vibration in Switched Reluctance Machines
Omer Gundogmus, Shuvajit Das, Anik Chowdhury, Abdul Wahab Bandarkar, Yilmaz Sozer
The University of Akron, United States

Session G10: High Speed and Bearingless Machines

1900 | Normalized Analytical Model of Stresses in a Surface Mounted Permanent Magnet Rotor
Martin Johnson, Kyle Hanson, Eric L. Severson
University of Wisconsin Madison, United States

1575 | Requirements for Full Passive Suspension on a Bearingless Motor with Electrodynamic Axial Stabilization and Radial Permanent Magnet Bearings
Guilherme Cavalcante Rubio, Yusuke Fujii, Akira Chiba
Tokyo Institute of Technology, Japan

1943 | Principles and Test Result of Novel Full Passive Magnetic Levitation Motor with Diamagnetic Disk
Yoshiki Ozawa¹, Yusuke Fujii¹, Akira Chiba¹, Hiroya Sugimoto², Haruhiko Suzuki³, Hannes Bleuler⁴
¹Tokyo Institute of Technology, Japan; ²Tokyo Denki University, Japan; ³Fukushima College, Japan; ⁴EPFL, Switzerland

2288 | Analysis and Design of Multi-Phase Combined Windings for Bearingless Machines
Anvar Khamitov, Eric L. Severson
University of Wisconsin Madison, United States

Session G11: Electrical Machines – 1

2315 | Design and Comparative Performance Analysis of Transverse Flux and Axial Flux Topologies for Permanent Magnet Synchronous Machines
Anik Chowdhury¹, Shuvajit Das¹, Tepppei Tsuda², Naoto Saito², Subrata Saha², Yilmaz Sozer¹
¹The University of Akron, United States; ²Aisin Corporation, Japan

2441 | Performance Comparison of Step Skew in Interior and Surface-Mount Permanent Magnet Machines
Md Sariful Islam, Amina Shrestha, Mohammad Islam
Halla Mechatronics, United States

1672 | Impact of Electric Field on Magnetic Flux Distribution in Electrical Machines with Very Large Size
Siqi Lin, Amir Ebrahimi, Jens Friebe
Leibniz Universität Hannover, Germany

2133 | PWM Torque Ripple Compensation for a Dual Three Phase Synchronous Machine
Claudio Bianchini¹, Ambra Torreggiani¹, Matteo Davoli², Alberto Bellini³, Ludovico Ortombina⁴, Nicola Bianchi⁴
¹University of Modena and Reggio Emilia, Italy; ²Raw Power srl, Italy; ³University of Bologna, Italy; ⁴University of Padova, Italy
<table>
<thead>
<tr>
<th>Session G12: Electrical Machines – 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2166</strong></td>
</tr>
<tr>
<td>Zbigniew Gmyrek¹, Andrea Cavagnino²</td>
</tr>
<tr>
<td>¹Lodz University of Technology, Poland; ²Politecnico di Torino, Italy</td>
</tr>
<tr>
<td><strong>2036</strong></td>
</tr>
<tr>
<td>Nathan Petersen, Timothy Slininger, Eric L. Severson</td>
</tr>
<tr>
<td>University of Wisconsin Madison, United States</td>
</tr>
<tr>
<td><strong>1394</strong></td>
</tr>
<tr>
<td>Lewis Chambers¹, Nick Baker¹, Mike Galbraith², Edward Spooner²</td>
</tr>
<tr>
<td>¹Newcastle University, United Kingdom; ²Fountain Design Limited, United Kingdom</td>
</tr>
<tr>
<td><strong>2045</strong></td>
</tr>
<tr>
<td>Fernando J.T.E. Ferreira, José Alberto, Aníbal T. de Almeida</td>
</tr>
<tr>
<td>University of Coimbra, Portugal</td>
</tr>
<tr>
<td><strong>2451</strong></td>
</tr>
<tr>
<td>Abdul Wahab Bandarkar¹, Muntasir Islam¹, Senol Sancar¹, Lavanya Vadamodala¹, Md Ehsanul Haque¹, Yilmaz Sozer¹, Reginald Garcia²</td>
</tr>
<tr>
<td>¹The University of Akron, United States; ²Future Motors, United States</td>
</tr>
<tr>
<td><strong>2263</strong></td>
</tr>
<tr>
<td>Carlos Madariaga¹, Juan Tapia¹, Nicolás Reyes¹, Werner Jara², Michele Degano³</td>
</tr>
<tr>
<td>¹University of Concepcion, Chile; ²Pontificia Universidad Católica de Valparaíso, Chile; ³University of Nottingham, United Kingdom</td>
</tr>
<tr>
<td><strong>2191</strong></td>
</tr>
<tr>
<td>Marco Biasion¹, João F. P. Fernandes², Paulo José da Costa Branco³, Silvio Vaschetto¹, Andrea Cavagnino¹, Alberto Tenconi¹</td>
</tr>
<tr>
<td>¹Politecnico di Torino, Italy; ²Universidade de Lisboa, Portugal</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Session G13: Electrical Machines – 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1918</strong></td>
</tr>
<tr>
<td>Yuzhi Zhang, Utkarsh Raheja, Pietro Cairoli</td>
</tr>
<tr>
<td>ABB Inc., United States</td>
</tr>
<tr>
<td><strong>1227</strong></td>
</tr>
<tr>
<td>Calvin Corey, William Wink</td>
</tr>
<tr>
<td>Leonard DRS Naval Power Systems, United States</td>
</tr>
</tbody>
</table>
Modeling of Rotor Flux Barriers in a Brushless Doubly-Fed Reluctance Machine
Shivang Agrawal, Hadi Chouhdry, Arijit Banerjee
University of Illinois at Urbana-Champaign, United States

Partial Discharge Analysis and Insulation Design of High Speed Slotless Machine for Aerospace Applications
Ritvik Chattopadhyay, Md Sariful Islam, Rajib Mikail, Iqbal Husain
1North Carolina State University, United States; 2Halla Mechatronics, United States; 3ABB, United States

Frequency-Domain Analysis and Design of Thomson-Coil Actuators
Bruno Lequesne, Tyler Holp, Steve Schmalz, Michael Slepian, Hongbin Wang
1E-Motors Consulting, LLC, United States; 2Eaton, United States

Design Optimization Procedure of Air-Cored Resonant Induction Machines
Zhao Jin, Matteo F. Iacchetti, Alexander C. Smith, Rajesh P. Deodhar, Yoshiyuki Komi, Ahmad Anad Abdulllah, Chiaki Umemura
1The University of Manchester, United Kingdom; 2IMRA Europe SAS UK Research Centre, United Kingdom; 3Aisin Seki Co., Ltd., Japan

Loss Minimization Control of an Electronic Pole Changing 4-Pole/2-Pole Induction Motor
Taohid Latif, Mohamed Zubair M. Jaffar, Iqbal Husain
1North Carolina State University, United States; 2FEV North America Inc., United States

Modelling and Build of an Integrated Linear Engine Generator Designed for Power Density
Ramn Moeini Korbekandi, Nick J. Baker, Mehmet Kulan, Dawei Wu
1Newcastle University, United Kingdom; 2University of Birmingham, United Kingdom

Simplified 3-D Hybrid Analytical Modelling of Magnet Temperature Distribution for Surface-Mounted PMSM with Segmented Magnets
1The University of Sheffield, United Kingdom; 2CRRC Zhuzhou Institute Co. Ltd., China

Optimization of IM Rotor Bars Inclination Angle Using Analytical Model in Free FEA Software
Thanh Tung To, Emad Roshandel, Amin Mahmoudi, Zhi Cao, Solmaz Kahourzade
1University of South Australia, Australia; 2Flinders University, Australia

2D Subdomain Model of the Ladder Linear Induction Machine with considering Saturation Effect
Emad Roshandel, Amin Mahmoudi, Solmaz Kahourzade
1Flinders University, Australia; 2University of South Australia, Australia

Loss Analysis of Induction Motors Fed by Inverters by Using Simple Models of Major and Minor Hysteresis Loops in Stator and Rotor Cores
Katsumi Yamazaki, Yoshito Sato, Keigo Terauchi
Chiba Institute of Technology, Japan

Analytical Magnetic Model for Variable-Flux Interior Permanent Magnet Synchronous Motors
Bingnan Wang, Kyung-Hun Shin, Yuki Hidaka, Shota Kondo, Hideaki Arita, Kazumasa Ito
1Mitsubishi Electric Research Laboratories, United States; 2Mitsubishi Electric Corporation, Japan

Hybrid Approach for the Modeling of Magnetic Force Excitations in Multipole Wind Turbine Generators considering Air Gap Imperfections
Alexander Kern, Christoph Mülner, Kay Hameyer, Jianning Dong
1RWTH Aachen University, Germany; 2Delft University of Technology, The Netherlands
Session G15: IPMSM and Synchronous Reluctance Machines

1031 | Comparative Study of Three-Phase and Dual Three-Phase Machines considering PWM Effect
Yawei Wang¹, Joshua Taylor², Berker Bilgin²
¹Huazhong University of Science and Technology, China; ²McMaster University, Canada

1204 | Space-Vector State Dynamic Model of the Synchronous Reluctance Motor considering Self, Cross-Saturation and Iron Losses
Angelo Accetta¹, Maurizio Cirrincione², Marcello Pucci¹, Antonino Sferlazza³
¹CNR-INM, Italy; ²University of the South Pacific, Italy; ³University of Palermo, Italy

1283 | Design of Notches on Rotor Surface to Minimize Cogging Torque in Dual-Layered IPMSM by Optimizing Squared Gap Flux Density Waveform
Marika Kobayashi, Shigeo Morimoto, Masayuki Sanada, Yukinori Inoue
Osaka Prefecture University, Japan

1617 | Permanent Magnet Eddy Current Loss Measurement at Higher Frequency and Temperature Effects under Ideal Sinusoidal and Non-Sinusoidal External Magnetic Fields
Nijan Yogal¹, Christian Lehmann²
¹Physikalisch-Technische Bundesanstalt, Germany; ²Technical University of Braunschweig, Germany

1852 | Combined Dimensional and Topology Optimization of Interior Permanent Magnet Synchronous Machine Rotors Using a Permanent Magnet Function Interpolation Method
Feng Guo, Ian P. Brown
Illinois Institute of Technology, United States

2154 | Comparative Analysis of Two Different Types of Blended Permanent Magnet Assisted Synchronous Reluctance Machine
Qingqing Ma¹, Ayman EL-Refaie¹, Alireza Fatemi², Thomas Nehl²
¹Marquette University, United States; ²General Motors, United States

2211 | Time-Efficient Multi-Physics Optimization Approaches for the Design of Synchronous Reluctance Motors
Christophe De Gréef¹, Virginie Kluyskens¹, François Henrotte¹, Christophe Versèle³, Christophe Geuzaine¹, Bruno Dehez¹
¹Université catholique de Louvain, Belgium; ²Université de Liège, Belgium; ³Alstom Belgium, Belgium

2241 | Variable-Magnetization Interior Permanent Magnet Motor Yield Widely Variable Flux Due to Small Magnetizing Current and Operating at High Power over a Wide Speed Range
Kazuto Sakai, Kyouhei Yoneda, Wataru Suzuki
Toyo University, Japan

Session G16: Other Synchronous Machines – 1

1040 | Multi-Objective Optimization of a Dual Stator Brushless Hybrid Excitation Motor Based on Response Surface Model and NSGA2
Xu Wang, Ying Fan, Xingchi Lu, Qiushuo Chen
Southeast University, China

1047 | Multi-Objective Optimization Design of Unequal Halbach Array Permanent Magnet Vernier Motor Based on Optimization Algorithm
Qiushuo Chen, Ying Fan, Yutong Lei, Xu Wang
Southeast University, China

1261 | Outer and Inner Rotor Line-Start Permanent-Magnet Synchronous Motors: An Electromagnetic and Thermal Comparison Study
M.F. Palangar¹, Wen L. Soong², A. Mahmoudi¹
¹Flinders University, Australia; ²University of Adelaide, Australia
Performance Comparison of Large-Scale Design-Optimised Non-Overlap and Overlap Winding Wound Rotor Synchronous Generators
Karen S. Garner, Maarten J. Kamper
Stellenbosch University, South Africa

Study on Power Tracking Excitation Control and Parameters Sensitivity of Dual-Excited Synchronous Generator
Guorui Xu¹, Zhenzhen Wang¹, Weili Li², Yang Zhan¹, Haisen Zhao¹, Yingli Luo¹
¹North China Electric Power University, China; ²Beijing Jiaotong University, China

Inter-Turn Short Circuit Fault Identification of Salient Pole Synchronous Generators by Descriptive Paradigm
Hossein Ehya¹, Arne Nysveen¹, Jose A. Antonino-Daviu², Bilal Akin³
¹Norwegian University of Science and Technology, Norway; ²Universitat Politècnica de València, Spain; ³The University of Texas at Dallas, United States

Comparison of Optimized Fault-Tolerant Modular Stator Machines with U-Shape and H-Shape Core Structure
Eddy Perez¹, Werner Jara¹, Carlos Madariaga², Juan Tapia², Gerd Bramerdorfer³, Javier Riedemann⁴, Ilya Petrov⁵, Juha Pyrhönen⁵
¹Pontificia Universidad Católica de Valparaíso, Chile; ²University of Concepcion, Chile; ³Johannes Kepler University Linz, Austria; ⁴The University of Sheffield, United Kingdom; ⁵Lappeenranta University of Technology, Finland

A Design Procedure for Hybrid Rotor PMSM to Achieve Wide Constant Power Speed Ratio
Dheeraj Bobba, Bulent Sarlioglu
University of Wisconsin Madison, United States

Design and Metamodel-Based Optimization of a High Power Density Wound Field Traction Motor
Nanjun Tang, Dominick Sossong, Ian P. Brown
Illinois Institute of Technology, United States

Design of High Torque Density Reduced-Rare-Earth Consequent Pole PMBLDC Motor for Ceiling Fan
Sharankumar Shastri, Utkarsh Sharma, Bhim Singh
Indian Institute of Technology Delhi, India

Design and Performance Comparison of Nine-Phase Ferrite Spoke Interior Permanent Magnet Machines with Concentrated Windings for Traction Applications
Zhiwei Zhang
The Ohio State University, United States

Performance Comparison of Consequent-Pole and Homopolar Consequent-Pole Bearingless Motors for Low Speed Applications
Hiroya Sugimoto, Miyabi Terashima
Tokyo Denki University, Japan
### Session G18: Switched Reluctance and Flux Switching Machines

<table>
<thead>
<tr>
<th>Session ID</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1183</td>
<td>A Novel MTPA Control Strategy for Multiple Torque Component Single Air Gap Magnetless Machines</td>
<td>Shaofeng Jia, Xiaozhuang Dong, Deliang Liang, Shuai Feng</td>
<td>Xi’an Jiaotong University, China</td>
</tr>
<tr>
<td>1223</td>
<td>Optimal Design of a Novel Double-Stator Linear-Rotary Flux-Switching Permanent-Magnet Generator for Offshore Wind-Wave Energy Conversion</td>
<td>Guozhen Zhang¹, Rui Nie¹, Jikai Si¹, Chun Gan², Yihua Hu³</td>
<td>¹Zhengzhou University, China; ²Huazhong University of Science and Technology, China; ³University of York, United Kingdom</td>
</tr>
<tr>
<td>1979</td>
<td>Six-Phase Switched Reluctance Motors with Small Torque Ripple, Radial Force Ripple, DC Current Ripple, Copper Loss, and Number of Switches</td>
<td>Takayuki Kusumi, Eiji Hiraki</td>
<td>Okayama University, Japan</td>
</tr>
<tr>
<td>2150</td>
<td>Design Methodology and Considerations to Energy Efficient Switched Reluctance Motor for Ceiling Fan Application</td>
<td>Vipin Kumar Singh, Utkarsh Sharma, Bhim Singh, Sharankumar Shastri</td>
<td>Indian Institute of Technology Delhi, India</td>
</tr>
<tr>
<td>2364</td>
<td>Reliability Models to Estimate Mean Time to Failure of Switched Reluctance Machines</td>
<td>Lavanya Vadamodala, Shuvajit Das, Anik Chowdhury, Abdul Wahab Bandarkar, Md Ehsanul Haque, Yilmaz Sozer</td>
<td>The University of Akron, United States</td>
</tr>
<tr>
<td>2472</td>
<td>An Experimental Verification of a Dual-Mode Reluctance Motor for Electric Vehicle Applications</td>
<td>Kyohei Kiyota¹, Haruka Isogai², Kenji Amei², Takahisa Ohji²</td>
<td>¹Tokyo Institute of Technology, Japan; ²University of Toyama, Japan</td>
</tr>
<tr>
<td>2532</td>
<td>Analysis and Benchmarking of Radial Flux Cycloidal Magnetic Gears with Reduced Permanent Magnet Piece Count Using Consequent Poles</td>
<td>Matthew Johnson¹, Shima Hasanpour², Matthew C. Gardner³, Hamid A. Toliyat²</td>
<td>¹U.S. Army Research Laboratory, United States; ²Texas A&amp;M University, United States; ³The University of Texas at Dallas, United States</td>
</tr>
</tbody>
</table>

### Session G19: Actuators, Axial Flux and Linear Machines

<table>
<thead>
<tr>
<th>Session ID</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1785</td>
<td>Statistical Analysis of Manufacturing Tolerances Effect on Axial-Flux Permanent Magnet Machines Cogging Torque</td>
<td>Andrés Escobar¹, Gonzalo Sánchez¹, Werner Jara¹, Carlos Madariaga², Juan Tapia², Michele Degano³, Javier Riedemann⁴</td>
<td>¹Pontificia Universidad Católica de Valparaiso, Chile; ²University of Concepcion, Chile; ³University of Nottingham, United Kingdom; ⁴The University of Sheffield, United Kingdom</td>
</tr>
<tr>
<td>2013</td>
<td>Design Optimization and Experimental Study of Coreless Axial-Flux PM Machines with Wave Winding PCB Stators</td>
<td>Peng Han¹, Damien Lawhorn¹, Yaser Chulaee³, Donovin Lewis¹, Greg Heins², Dan M. Ionel¹</td>
<td>¹University of Kentucky, United States; ²Regal Beloit Corporation, Australia</td>
</tr>
<tr>
<td>2214</td>
<td>Design of a High Speed Printed Circuit Board Coreless Axial Flux Permanent Magnet Machine</td>
<td>Federico Marcolini, Giulio De Donato, Fabio Giulii Capponi, Federico Caricchi</td>
<td>Sapienza University of Rome, Italy</td>
</tr>
</tbody>
</table>
2160 | Design and Analysis of Double-Sided Thomson Coil Actuator for Extra Fast Opening Operation
Ali Al-Qarni, Ayman El-Refaie
Marquette University, United States

2056 | Permanent Magnet Linear Generator Design for Surface Riding Wave Energy Converters
Farid Naghavi¹, Shrikesh Sheshaprasad¹, Matthew Gardner², Aghamarshana Meduri¹, HeonYong Kang¹, Hamid Toliyat¹
¹Texas A&M University, United States; ²The University of Texas at Dallas, United States

2342 | On the Design and Stability of a Reluctance Actuator for Precision Motion Systems
Mohammad Al Saaideh, Natheer Alatawneh, Mohammad Al Janaideh
Memorial University, Canada

1172 | Planar Levitation and Propulsion of a Solid-State Craft over Conducting Surfaces
Andrew W. Meldrum, Will Robertson, Wen L. Soong
The University of Adelaide, Australia

1075 | Force and Torque Assessment in a Rotating to Linear Motion Magnetic Converter with Gearing Capability
Mauro Andriollo, Simone Bernasconi, Andrea Tortella
University of Padova, Italy

Session G20: Electrical Machines – 4

1196 | Additively Manufactured Hollow Conductors for High Specific Power Electrical Machines: Aluminum vs Copper
Fan Wu, Ayman M. El-Refaie, Ali Al-Qarni
Marquette University, United States

1258 | Rotor Loss and Temperature Field of Synchronous Condenser under Single-Phase Short Circuit Fault Affected by Different Materials of Rotor Slot Wedge
Guorui Xu, Peidong Hu, Zhiqiang Li, Haisen Zhao, Yang Zhan
North China Electric Power University, China

Christoph Dobler, Daniel Wöckinger, Gerd Bramerdorfer, Gereon Goldbeck, Wolfgang Amrhein
Johannes Kepler University Linz, Austria

1252 | Characteristics Evaluation of Magnetic Multiple Spur Gear for High Speed Motor Drive System
Kohei Aiso¹, Kan Akatsu², Yasuaki Aoyama³
¹Shibaura Institute of Technology, Japan; ²Yokohama National University, Japan; ³Hitachi, Ltd., Japan

1992 | Design Optimization of a Very High Power Density Motor with a Reluctance Rotor and a Modular Stator Having PMs and Toroidal Windings
Peng Han¹, Murat G. Kesgin¹, Dan M. Ionel¹, Rohan Gosalia², Nakul Shah², Charles J. Flynn², Chandra S. Goli³, Somasundaram Essakiappan³, Madhav Manjrekar⁴
¹University of Kentucky, United States; ²QM Power, Inc., United States; ³University of North Carolina Charlotte, United States

Session G21: Noise and Vibrations in Electric Machines – 2

1212 | Transient Stray Flux Analysis via MUSIC Methods for the Detection of Uniform Gearbox Teeth Wear Faults
Israel Zamudio-Ramirez¹, Roque A. Osornio-Rios¹, Jose Antonino-Daviu²
¹Universidad Autonoma de Queretaro, Mexico; ²Universitat Politecnica de Valencia, Spain
1302 | Analytical and Experimental Investigations of Magnetostriction Influence on Strain Measurement in Switched Reluctance Machines
Yifei Cai, Haruki Sobue, Candra Adi Wigna, Akira Chiba, Kunihiro Senda, Souichiro Yoshizaki
1Tokyo Institute of Technology, Japan; 2JFE Techno-Research Corporation, Japan; 3JFE Steel Corporation, Japan

1585 | Reduction of Both of Radial Force and Torque Ripple in Double Inverter Fed PMSM
Takumi Soeda, Hitoshi Haga
Nagaoka University of Technology, Japan

1901 | Study on IPMSM Rotor Shape for Reduction of Harmonics and Vibration
Seung-Hyeon Lee, In-Jun Yang, Si-Woo Song, Won-Ho Kim, Ik-sang Jang
1Gachon University, Korea; 2Hanyang University, Korea; 3Hyundai Mobis, Korea

1995 | Vibration Performance of a Power Electronic Transformer under Different Phase-Shift Modulation Methods
Xiaokang Peng, Zicheng Liu, Dong Jiang
Huazhong University of Science and Technology, China

2127 | Demagnetization Detection in PMSMs Using Search Coils Exploiting Machine’s Symmetry
Marcos Orviz Zapico, David Diaz Reigosa, Hyeon Jun Lee, Muhammad Saad Rafaq, Sang Bin Lee, Fernando Briz del Blanco
1University of Oviedo, Spain; 2Korea University, Korea

2163 | Research on High Frequency Vibration Reduction Using Carrier Phase Shifted PWM for 4*3-Phase Windings Permanent Magnet Synchronous Motor
She Yan, Qiyuan Wang, Yunsong Xu, Zicheng Liu, Haiyang Fang, Dong Jiang
Huazhong University of Science and Technology, China

2266 | Air Gap Length Detection Method by Analysing Third-Order Harmonic Component of No-Load Line-Line Voltages on Three-Group and Three-Phase PMSMs
Kodai Okazaki, Kan Akatsu, Kan Yang
1Mitsubishi Electric Co., Ltd., Japan; 2Yokohama National University, Japan

Session G22: Modeling of Electric Machines – 3

1097 | Analytical Modeling and Design Optimization of a Vernier Permanent Magnet Motor
Bingnan Wang, Lei Zhou, Hongyu Wang, Chungwei Lin
1Mitsubishi Electric Research Laboratories, United States; 2The University of Texas at Austin, United States

1207 | Characteristic Analysis of IPMSM for EV Traction considering the Effect of Field and Armature Excitations on AC Copper Loss
Soo-Hwan Park, Jun-Woo Chin, Kyoung-Soo Cha, Jun-Yeol Ryu, Myung-Seop Lim
Hanyang University, Korea

1236 | Cost-Efficient 2D Analysis for PM Eddy Current Loss in PMSM by Coupled A-Φ and T-Ω Method
Jun-Yeol Ryu, Jun-Woo Chin, Myung-Seop Lim
Hanyang University, Korea

1237 | Efficiency Analysis of Brushless Doubly-Fed Induction Generator Based on Improved Steady-State Equivalent Circuit
Yangsheng Zhang, Yi Liu, Wei Xu, Jose Rodriguez
1Huazhong University of Science and Technology, China; 2Universidad Andres Bello, Chile
1646 | Development and Evaluation of a Power Hardware-in-the-Loop (PHIL) Emulator Testbench for Aerospace Applications
He Song¹, John Noon¹, Igor Cvetkovic¹, Bo Wen¹, Srdjan Srdic², Gernot Pammer², Dushan Boroyevich¹, Rolando Burgos¹
¹Virginia Polytechnic Institute and State University, United States; ²EGSTON Power Electronics, Austria

2380 | A Generalized Prandtl-Ishlinskii Model for Hysteresis Modeling in Electromagnetic Devices
Mohammad Al Saaideh, Natheer Alatawneh, Mohammad Al Janaideh
Memorial University, Canada

Session G23: High Speed Machines – 1

1144 | Rotor Reinforcement in High-Speed Motors by Polymer Composites
Anthony Coppola, Alireza Fatemi
General Motors, United States

1537 | Modeling and Optimal Design of a Very High Speed Motor Slotless Technology with Toroidal Winding for Serial Production
Stephane Tavernier¹, Christophe Espanet¹, Gael Andrieux²
¹Moving Magnet Technologies, France; ²Compact Power Motion GmbH, Germany

1687 | Design Approach of Hairpin Winding Motor with High Parallel Path Numbers
Shaohong Zhu, Krzysztof Paciura, Richard Barden
Cummins Inc., United Kingdom

1697 | Suppression of Winding AC Losses in High-Speed Permanent Magnet Machines by Novel Transposition Technologies
Xinyue Chen, Haiyang Fang, Dawei Li, Ronghai Qu, Xinggang Fan, Haobo Hu
Huazhong University of Science and Technology, China

1781 | High Speed Permanent Magnet Machine Design for Optimum Volumetric Power Density
Zhentao Stephen Du, Jagadeesh Tangudu
Raytheon Technologies Research Center, United States

1891 | Suspension Force Design Guidelines for Bearingless Permanent Magnet Machines
Bharat Ramadas, Eric L. Severson
University of Wisconsin Madison, United States

Session G24: Electrical Machines – 5

2073 | Bearingless Generator Design and Optimization for High-Speed Applications
Imthiaz Ahmed, Eric L. Severson
University of Wisconsin Madison, United States

2080 | Modular Fault-Tolerant Machine Design with Improved Electromagnetic Isolation for Urban Air Mobility (UAM) Aircraft
James Swanke, Hao Zeng, Thomas M. Jahns
University of Wisconsin Madison, United States

2483 | Design and Analysis of a High Specific Power Outer Rotor Surface Mounted Permanent Magnet Machine Equipped with Additively Manufactured Windings
Ali Al-Qarni, Ayman EL-Refaie, Fan Wu
Marquette University, United States
1532 | Hybrid Spoke Permanent Magnet Synchronous Generator Design for Wind Power Generation System
Dong-Ho Kim¹, Su-Yong Kim², In-Jun Yang¹, Si-Woo Song¹, Ju Lee¹, Won-Ho Kim³
¹Hanyang University, Korea; ²Korea Electronics Technology Institute, Korea; ³Gachon University, Korea

C.J.J. Labuschagne, M.J. Kamper
Stellenbosch University, South Africa

1985 | Modular Modeling and Distributed Control of Permanent-Magnet Modular Motor Drives (MMDs) for Electric Aircraft Propulsion
Hao Zeng, James Swanke, Thomas M. Jahns, Bulent Sarlioglu
University of Wisconsin Madison, United States

Session G25: High Speed Machines – 2

2027 | On the Modeling of Bearing Voltage and Current in PWM Converter-Fed Electric Machines Using Electromagnetic Finite Element Analysis
Peng Han¹, Yibin Zhang¹, Murat G. Kesgin¹, Greg Heins², Dean Patterson², Mark Thiele², Dan M. Ionel¹
¹University of Kentucky, United States; ²Regal Beloit Corporation, Australia

2130 | Radial and Axial Inlet and Outlet Design for End Winding Cooling of High-Speed Integrated Flux-Switching Motor-Compressor
Leyue Zhang, Hao Ding, Ahmed Hembel, Gregory Nellis, Bulent Sarlioglu
University of Wisconsin Madison, United States

2138 | Application of Flat Rectangular Wire Concentrated Winding for AC Loss Reduction in Electrical Machines
Shaohong Zhu, Krzysztof Paciura, Richard Barden
Cummins Inc., United Kingdom

2387 | Multiphysics Optimization Model to Design High-Power Ultra-High-Speed Machine for Portable Mechanical Antenna Application
Md Khurshedul Islam, Seungdeog Choi
Mississippi State University, United States

2403 | Rotor Design for 2 Pole Bearingless Interior Permanent Magnet Slice Motor
Krishan Kant, David L. Trumper
Massachusetts Institute of Technology, United States

2408 | Analytical Calculation of the Mechanical Stress on IPMSM Bridges with Decomposition of the Centrifugal Force
Guoyu Chu¹, Rukmi Dutta¹, John Fletcher¹, Howard Lovatt², M.F. Rahman¹
¹University of New South Wales, Australia; ²CSIRO, Australia

2492 | Modelling, Analysis and Design Considerations of Multi-Phase Bearingless Permanent Magnet Synchronous Machine
Alessandro Marfoni, Mauro Di Nardo, Seamus Garvey, Michele Degano, Rajiv Vashisht, Robert Turnbull, Chris Gerada
University of Nottingham, United Kingdom
Topic H: Electric Drives

Session H01: PM Motor Drives – 1

2120 | Practical Compensation Strategy for Accurate Torque Control in Mass-Produced High-Speed Traction IPM E-Drives
Ran Cao¹, Dakai Hu², Yue Cao¹
¹Oregon State University, United States; ²The MathWorks, Inc., United States

2186 | Torque-Sensorless Identification of IPMSM Torque Map
Hyung-June Cho¹, Joohyun Lee¹, Yong-Cheol Kwon², Seung-Ki Sul¹
¹Seoul National University, Korea; ²PLECKO Co., Ltd., Korea

2126 | Direct Flux and Load Angle Vector Control of Permanent Magnet Synchronous Motors
Sandro Rubino, Fabio Mandrile, Luisa Tolosano, Eric Armando, Radu Bojoi
Politecnico di Torino, Italy

1888 | Modeling and Compensation of Nonlinearity in Voltage-Source-Inverters Fed Dual Three-Phase PMSM Drives
Kailiang Yu, Zheng Wang, Pengcheng Liu, Yihan Chen
Southeast University, China

Session H02: Control for Electric Drives

1079 | Gradient-Based Predictive Pulse Pattern Control
Mirza Abdul Waris Begh¹, Petros Karamanakos¹, Tobias Geyer²
¹Tampere University, Finland; ²ABB System Drives, Switzerland

1136 | A Computationally Efficient Robust Direct Model Predictive Control for Medium Voltage Induction Motor Drives
Andrei Tregubov¹, Petros Karamanakos¹, Ludovico Ortombina²
¹Tampere University, Finland; ²University of Padova, Italy

1553 | High Frequency Signal Injection Sensorless Control of Finite-Control-Set Model Predictive Control with Deadbeat Solution
Ximeng Wu¹, Z.Q. Zhu¹, Nuno M.A. Freire²
¹The University of Sheffield, United Kingdom; ²Siemens Gamesa Renewable Energy A/S, Denmark

2375 | A Direct Model Predictive Control Strategy for High-Performance Synchronous Reluctance Motor Drives
Jacopo Riccio¹, Petros Karamanakos², Shafiq Odhano³, Mi Tang¹, Mauro Di Nardo¹, Pericle Zanchetta¹,⁴
¹University of Nottingham, United Kingdom; ²Tampere University, Finland; ³Newcastle University, United Kingdom; ⁴Università degli Studi di Pavia, Italy

Session H03: New Technologies, Sensors, Reliability and Testing

1847 | Multi-Core Microcontroller Hardware in the Loop System for Electric Machine Control
Nicholas Krause¹, Antonio Di Gioia², Ian P. Brown¹
¹Illinois Institute of Technology, United States; ²EEMA US Inc., United States

2075 | Design of a Low-Latency Power Electronics-Based Power-HIL System for an EV Motor Controller
Troy Eskilson, Carl Ngai Man Ho
University of Manitoba, Canada
1073 | Inverter-Embedded Partial Discharge Testing for Reliability Enhancement of Stator Winding Insulation in Low Voltage Machines
Hyeon-Jun Lee¹, Hanju Kim¹, Jigyun Jeong¹, Kibok Lee², Sang Bin Lee¹, Greg C. Stone³
¹Korea University, Korea; ²Incheon National University, Korea; ³Iris Power - A Qualitrol Company, Canada

2302 | E-Drive SiC MOSFET Inverter with Self Calibrating VON-Based Junction Temperature Estimator
Fausto Stella, Paolo Pescetto, Gianmario Pellegrino
Politecnico di Torino, Italy

Session H04: Sensorless Control of Electric Drives – 1

2542 | Skin Effect of Squirrel Cage Induction Motor under High Frequency Signal Injection
Joon-Hee Lee¹, Yong-Cheol Kwon², Seung-Ki Sul¹
¹Seoul National University, Korea; ²Plecko Co, Ltd., Korea

1755 | Design and Analysis of PLL Speed Estimator for Sensorless Rotor-Flux Oriented Control of Induction Motor Drives
Prasun Mishra¹, Cristian Lascu¹, Michael Møller Bech¹, Bjorn Rannestad², Stig Munk-Neilsen
¹Aalborg University, Denmark; ²KK Wind Solutions, Denmark

1030 | High Frequency Injection Transient Disturbance Mitigation for Sensorless Control of Salient Pole Machines
Zhendong Zhang, Jacob Lamb
Rockwell Automation, United States

1557 | Analysis of Rotor Eccentricity Effects on Saliency Tracking Based Sensorless Control of Permanent Magnet Synchronous Machine
Ximeng Wu¹, Z.Q. Zhu¹, Yang Chen¹, Zhanyuan Wu²
¹The University of Sheffield, United Kingdom; ²Siemens Gamesa Renewable Energy, United Kingdom

Session H05: Sensorless Control of Electric Drives – 2

2493 | Switching Frequency Signal-Injection Sensorless Control Robust to Non-Ideal Characteristics of Inverter System for Dual Three-Phase PMSM
Yoon-Ro Lee, Jiwon Yoo, Seung-Ki Sul
Seoul National University, Korea

2510 | Gain Scheduling of Full-Order Flux Observer for Sensorless PMSM Drives considering Magnetic Spatial Harmonics
Jiwon Yoo, Inhwi Hwang, Yoon-Ro Lee, Seung-Ki Sul
Seoul National University, Korea

2519 | Rotor Initial Position Estimation Method of SMPMSM with Polarity Detection Based on Cross-Coupling Inductance Variation
Hwigon Kim, Joohyun Lee, Seung-Ki Sul
Seoul National University, Korea

2257 | Sensorless Control of a High-Speed PMSM with Rapid Acceleration for Air Compressors Using a High-Order Extended State Observer
Mingjin Hu¹, Wenfei Yu¹, Jiaxing Lei¹, Zheng Wu¹, Wei Hua², Yinfeng Hu²
¹Southeast University - Nanjing, China; ²Southeast University - Yancheng, China
### Session H06: Electric Drive Switching

**2122 | Advances on Analysis, Modeling and Accurate Self-Commissioning Compensation of Inverter Dead-Time Distortion Based on a Physical Model**  
Massimiliano Biason¹, Sandro Calligaro², Mattia Iurich¹, Roberto Petrella¹, Amir Shahdadi¹  
¹University of Udine, Italy; ²Free University of Bozen, Italy

**1495 | A New Space-Vector PWM Technique of Two-Level Inverter Fed Asymmetrical Six-Phase Machine: Analysis and Performance Evaluation**  
Sayan Paul, Kaushik Basu  
Indian Institute of Science, India

**1963 | New PWM Switching Strategy for a Dual Inverter Fed Open Winding Motor Drive System**  
Yuto Maeda¹, Hiroaki Matsumori¹, Takashi Kosaka¹, Nobuyuki Matsui¹, Hiroki Iwai¹, Teppei Tsuda¹, Subrata Saha¹  
¹Nagoya Institute of Technology, Japan; ²Aisin Corporation, Japan

**2141 | A Real-Time Sinusoidal Voltage-Adjustment Power Supply System Based on Interleaved BUCK Converters with Enhanced Reference-Tracking Capability**  
Xiaofeng Ding, Zhihui Zhao, Zhenyu Shan, Xinrong Song  
Beihang University, China

### Session H07: PM Motor Drives – 2

**2246 | Variable DC-Link Control Strategy for Maximum Efficiency of Traction Motor Drives**  
Paolo Pescetto¹, Andres Sierra-Gonzalez², Elena Trancho², Gianmario Pellegrino¹  
¹Politecnico di Torino, Italy; ²Basque Research and Technology Alliance, Spain

**2381 | Control of Dual Three-Phase IPMSM Drive with Cascaded DC-Link Capacitors for Third Generation EV**  
Andres Sierra-Gonzalez¹, Paolo Pescetto², Elena Trancho¹, Edorta Ibarra³, Gianmario Pellegrino², Fernando Alvarez-Gonzalez¹  
¹Basque Research and Technology Alliance, Spain; ²Politecnico di Torino, Italy; ³University of the Basque Country, Spain

**2261 | A Novel Low-Speed Direct-Drive PMSM Control Strategy Based on a Two-DOF Structure**  
Kun Cai¹, Jie Hu¹, Mingjin Hu¹, Danfeng Sun¹, Huajun Zhou¹, Kai Liu¹, Hao Hua³, Wei Hua¹  
¹Southeast University, China; ²Shanghai Aerospace Control Technology Institute, China; ³Shanghai Jiao Tong University, China

**2445 | Integrated High-Frequency SiC Based Modular Multi Three-Phase PMSM Drive for Automotive Range Extender**  
Nicola Bianchi¹, Sandro Calligaro², Giorgio Maldini³, Mattia Marson⁴, Mattia Iurich⁵, Roberto Petrella⁶  
¹University of Padova, Italy; ²Free University of Bozen, Italy; ³Metasystem s.p.a., Italy; ⁴Koala Electronics s.r.l., Italy; ⁵University of Udine, Italy

### Session H08: Electric Drives

**2368 | Selection of Rotor Position Sensor Resolution for Variable Frequency Drives Utilizing Fixed-Position-Based Speed Estimation**  
Luigi Danilo Tornello¹, Giacomo Scelba¹, Giulio De Donato², Fabio Giulii Capponi², Giuseppe Scarcella¹, Mark Harbaugh¹  
¹University of Catania, Italy; ²Sapienza University of Rome, Italy; ³Rockwell Automation, United States

**1262 | A Simple PWM Strategy for Three-Level NPC Converters in Aircraft Electric Starter/Generator System with Improved DC-Link Voltage Utilization and Reduced Common-Mode Voltage**  
Feng Guo¹, Tao Yang¹, Seang Shen Yeoh¹, Serhiy Bozhko¹, Patrick Wheeler¹, Ahmed M. Diab²  
¹University of Nottingham, United Kingdom; ²University of Nottingham Ningbo, China
**Performance Analysis of a Fault Isolation System for Fault-Tolerant Voltage-Fed PWM Motor Drives**
Luigi Danilo Tornello¹, Giacomo Scelba¹, Andrea Spampinato², Gianluigi Forte²
¹University of Catania, Italy; ²STMicroelectronics, Italy

**Evaluation of Topologies and Active Control Methods for Overvoltage Mitigation in SiC-Based Motor Drives**
Mohamed S. Diab, Wenzhi Zhou, Xibo Yuan
University of Bristol, United Kingdom

**Design and Benchmark of Passive and Active Inductors for a 7.5 kW Motor Drive**
Zhe Kong¹, Qian Wang², Guorong Zhu¹, Haoran Wang², Huai Wang²
¹Wuhan University of Technology, China; ²Aalborg University, Denmark

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### Session H09: Induction Motor Drives

**A Multilevel Open-End Winding Six-Phase Induction Motor Drive Topology Based on Three Two-Level Three-Phase Inverters**
Emerson de L. Soares¹, Ayslan C.N. Maia², Cursino B. Jacobina¹, Nayara B. de Freitas³, Nady Rocha⁴, Antonio M.N. Lima¹
¹Federal University of Campina Grande, Brazil; ²Federal Institute of Education, Science and Technology of Ceará, Brazil; ³INESC TEC, Portugal; ⁴Federal University of Paraíba, Brazil

**Analysis and Control of Six Switch Inverter Symmetrical Two-Phase Induction Motor (STPIM) Drive with Front End Single-Phase Boost Rectifier**
Josiah O. Haruna, Olorunfemi Ojo
Tennessee Tech University, United States

**Evaluation of the Output Voltage Harmonics of Typical PWM Methods in a Dual-Inverter Fed Open-End Winding Induction Motor with a Floating-Capacitor**
Akihito Mizukoshi¹, Hitoshi Haga¹, Eiichi Sakasegawa²
¹Nagaoka University of Technology, Japan; ²National Institute of Technology, Kagoshima College, Japan

**Parameter Identification of Inverter-Fed Induction Machines at Standstill Based on Signal Injection**
Anh Tan Nguyen, Van Nam Nguyen, Dong-Choon Lee
Yeungnam University, Korea

**Regenerating-Mode Stabilization of Indirect-Field-Orientation-Controlled Induction Motor for Inertial Load Drive**
Masaki Nagataki¹, Keiichiro Kondo¹, Osamu Yamazaki², Kazuaki Yuki², Yosuke Nakazawa²
¹Waseda University, Japan; ²Toshiba Corporation, Japan

**Field Weakening Operation of Open-Winding Induction Motor Dual Drives Using a Floating Capacitor Bridge Inverter**
Saeed Wdaan, Chatumal Perera, John Salmon
University of Alberta, Canada

**Torque Pulsation Reduction in Three-Phase Doubly Fed Induction Machine for Wireless Energy Transfer Applications**
Gabriele Rizzoli, Michele Mengoni, Giacomo Sala, Luca Zarri, Angelo Tani
University of Bologna, Italy
Session H10: PM Motor Drives – 1

1408 | Improved Controller Optimization of Flux-Weakening Strategy for Salient Permanent-Magnet Synchronous Motor Based on Genetic Algorithm
Moustafa Magdi Ismail1,2, Wei Xu2, Yi Liu2, Abdul Khalique Junejo3, Mohamed G. Hussien4
1Minia University, Egypt; 2Huazhong University of Science and Technology, China;
3Quaid-e-Awam University of Engineering, Science and Technology, Pakistan; 4Tanta University, Egypt

2347 | Model Reference Adaptive Current Control Method for Dual Three Phase Permanent Magnet Synchronous Machine
Anik Chowdhury, Md Ehsanul Haque, Shuvajit Das, Okan Boler, Yilmaz Sozer
The University of Akron, United States

2550 | Comprehensive Efficiency Analysis of Current Source Inverter Based on CSI-Type Double Pulse Test and Genetic Algorithm
Feida Chen, Sangwhee Lee, Thomas M. Jahns, Bulent Sarlioglu
University of Wisconsin Madison, United States

1965 | Torque Ripple Minimization of PMSM Drive with Speed Ripple Feedback considering Non-Linearities of PMSM
Byung Ryang Park, Gyu Cheol Lim, Jonghun Choi, Cheolmin Hwang, Jung-Ik Ha
Seoul National University, Korea

1340 | Deadbeat Predictive Current Control considering Inverter Nonlinearity in Permanent Magnet Synchronous Machine
Xin Yuan, Jiahao Chen, Yuefei Zuo, Christopher H.T. Lee
Nanyang Technological University, Singapore

1364 | Harmonics Compensation for High Reliability under Grid Voltage Distortion Using Electrolytic Capacitor-Less Dual Inverter with Periodical Torque Fluctuation Load
Yuuki Ohno, Hitoshi Haga
Nagaoka University of Technology, Japan

2365 | Hall-Effect Sensors as Multipurpose Devices to Control, Monitor and Diagnose AC Permanent Magnet Synchronous Machines
Daniel Fernandez1, David Reigosa1, Yonghyun Park2, Sangbin Lee3, Fernando Briz1
1University of Oviedo, Spain; 2Electree Co. Ltd., Korea; 3Korea University, Korea

Session H11: Control of Electric Drives – 1

1166 | Input-Output Feedback Linearization Control with On-Line Inductances Estimation of Synchronous Reluctance Motors
Angelo Accetta1, Maurizio Cirrincione2, Filippo D'Ippolito3, Marcello Pucci1, Antonino Sferlazzo3
1CNR-INM, Italy; 2University of the South Pacific, Fiji; 3University of Palermo, Italy

2327 | Pseudo Multi Level Space Vector Modulation Technique for Multi Source Inverters
O. Salari, K. Hashtrudi Zaad, A. Bakhshai, P. Jain
Queen’s University, Canada

1855 | Comparison of Fault-Tolerant Control Methods Reducing Torque Ripple of Multi-Phase BLDC Motor Drive System under Open-Phase Faults
Hyeoncheol Park, Taeyun Kim, Yongsug Suh
Jeonbuk National University, Korea

1921 | Parameter Sensitivity of Deadbeat Flux Vector Control for Six-Step Operation of Permanent Magnet Synchronous Machines
Marc S. Petit1, Bulent Sarlioglu2
1Miller Electric Mfg., LLC, United States; 2University of Wisconsin Madison, United States
<table>
<thead>
<tr>
<th>Session H12: Control of Electric Drives – 2</th>
</tr>
</thead>
</table>
| 2153 | **Finite Control Set Model-Based Predictive Current Control with Variable Sampling Interval for Induction Machine**  
Qing Chen¹, Xiaonan Gao¹, Peter Stolze², Ralph Kennel¹  
¹Technical University of Munich, Germany; ²MAN Energy Solutions SE, Germany |
| 1838 | **Two-Degree-of-Freedom Quasi-PIR Controller for Smooth Speed Control of Permanent Magnet Vernier Machine**  
Yuefei Zuo, Jingwei Zhu, Xin Yuan, Christopher H.T. Lee  
Nanyang Technological University, Singapore |
| 2491 | **Online PI Current Controller Tuning Based on Machine High-Frequency Parameters**  
Diego F. Laborda, Juan Manuel Guerrero, Marcos Orviz Zapico, Daniel Fernández, David Diaz Reigosa, Fernando Briz  
University of Oviedo, Spain |
| 1799 | **Parameter-Free Predictive Current Control for Synchronous Machine Controlled by High-Frequency Signal Injection Sensorless**  
Hyeon-Seong Kim, Kibok Lee  
Incheon National University, Korea |
| 1386 | **Three-Phase Motor Drive Topology with the Fault-Tolerant Capability of Open-Circuit on the Multiplexing Bridge**  
Xiangwen Sun, Zhicheng Liu, Zhekai Li, Qianchen Sun, An Li, Dong Jiang  
Huazhong University of Science and Technology, China |
| 1608 | **Sensorless Acceleration Estimation and Acceleration Feedback Control to Improve the Disturbance Torque Rejection on Galvano Motor System**  
Yi-Jen Lin¹, Po-Huan Chou², Chi-Jun Wu¹, Shih-Chin Yang¹  
¹National Taiwan University, Taiwan; ²Industrial Technology Research Institute, Taiwan |

**Session H13: Sensorless Control of Drives**

| 1186 | **High-Precision Sensorless Control Method with Fast Dynamic Response for High-Speed PMSM Based on Discrete-Time Back-EMF Deadbeat Observer**  
Zhihao Song¹, Wenxi Yao¹, Kevin Lee²  
¹Zhejiang University, China; ²Eaton, United States |
| 2354 | **Phase Current Sensorless Control of Switched Reluctance Machines Using Dynamic Interleaving**  
Md Ehsanul Haque¹, Anik Chowdhury¹, Okan Boler¹, Shuvajit Das¹, Yilmaz Sozer¹, Fernando Venegas², David Colavincenzo²  
¹The University of Akron, United States; ²Bendix Commercial Vehicle Systems, United States |
1084 | Low-Speed Position Estimation of the Brushless Synchronous Starter/Generator by Using the Main Exciter as a Quasi Resolver
Shuai Mao¹, Jianqiu Li¹, Xu Han², Weiguo Liu², Zunyan Hu¹, Liangfei Xu¹, Minggao Ouyang¹
¹Tsinghua University, China; ²Northwestern Polytechnical University, China

1085 | Adaptive Observer Design for Wide-Speed Sensorless IPMSM Drives via Equivalent Control Method
Qilian Lin, Ling Liu, Han Song, Dongsong Jin, Deliang Liang, Shaofeng Jia
Xi’an Jiaotong University, China

1531 | Experimental Investigation on the Self-Sensing Capability of Synchronous Machines for Signal Injection Sensorless Drives
Matteo Berto, Luigi Alberti, Silverio Bolognani
University of Padova, Italy

2128 | Use HF Signal Injection for Simultaneous Rotor Angle, Torque and Temperature Estimation in PMSMs
Marcos Orviz Zapico, David Diaz Reigosa, Diego Fernández Labora, Maria Martínez Gómez, Juan Manuel Guerrero Muñoz, Fernando Briz del Blanco
University of Oviedo, Spain

1694 | Rotor Temperature Estimation for Saliency-Based Control of Induction Motors Using Symmetrical Transient Resistance
Eduardo Rodriguez Montero¹, Markus Vogelsberger², Thomas Wolbank¹
¹Technical University of Vienna, Austria; ²Bombardier Transportation Austria GmbH, Austria

Session H14: Diagnostics, Fault Tolerance and Reliability in Electric Drives

1957 | Current-Sensor and Switch-Open Fault Diagnosis Based on Discriminative Machine Learning Model for PMSM Driving System
Jae-Hoon Shim¹, Jun Lee², Jung-Ik Ha¹
¹Seoul National University, Korea; ²Samsung Electronics, Korea

1344 | A Novel SPWM-Based Common-Mode Voltage Elimination Modulation Method for Dual Three-Phase Motors
Yang Huang¹, Ximu Zhang¹, Jared Walden¹, Hua Bai¹, Fanning Jin², Xiaodong Shi², Bing Cheng²
¹University of Tennessee Knoxville, United States; ²Mercedes-Benz R&D North America, Inc., United States

1210 | A Novel Ring-Shaped Fractal Antenna for Partial Discharge Detection
Yinka Leo Ogundiran, Antonio Griffio, Shubham Sundeep, Fernando Alvarez Gonzalez, Jiabin Wang
The University of Sheffield, United Kingdom

1234 | An On-Line DC-Link Capacitance Estimation Method for Motor Drive System Based on Intermittent Active Control Strategy
Tianze Meng, Pinjia Zhang
Tsinghua University, China

2078 | Time-Domain Based Diagnosis of Stator Incipient Faults in DTC Driven Induction Motors Using External ElectroMagnetic Signatures
Hassan H. Eldeeb¹,²,³, Caleb Secrest¹, Haisen Zhao²,⁴, Osama A. Mohammed²
¹Borg Warner Inc., United States; ²Florida International University, United States; ³Ain Shams University, Egypt; ⁴North China Electric Power University, China

2204 | Comparative Analysis of Torque Pulsations Measurement Methods for PMSM Drives
Maria Martinez, Diego F. Laborda, David Reigosa, Fernando Briz
University of Oviedo, Spain
Session H15: Medium Voltage and Drive Applications

1198 | Vibration and Loss Reduction of Permanent Magnet Synchronous Motor Driven by Synchronous PWM Control with Carrier Wave Phase Shifts
Takafumi Hara¹, Shun Taniguchi², Toshiyuki Ajima¹, Masanori Sawahata¹, Masahiro Hori¹, Tsukagoshi Takaya², Katsuhiro Hoshino²
¹Hitachi, Ltd., Japan; ²Hitachi Astemo, Ltd., Japan

1524 | Transient Hall Sensor Fault Compensation for Hall-Based Field Oriented Control Motor Drive
Heng-Ching Lin, Jyun-You Chen, Guan-Ren Chen, Shih-Chin Yang
National Taiwan University, Taiwan

Session H16: Electric Drive Applications

1382 | Adaptive-Observer-Based Sensor Fault Resilient Control for Single-Phase Grid-Connected Converters in High-Speed Railway Traction Systems
Jinhui Xia¹, Ze Li¹, Yuanbo Guo², Xiaohua Zhang²
¹Zhejiang University, China; ²Dalian University of Technology, China

2037 | A Stable and Robust DC Power System for More Electric Aircraft
Galina Mirzaeva¹, Dmitry Miller¹, Graham Goodwin¹, Patrick Wheeler²
¹The University of Newcastle, Australia; ²University of Nottingham, United Kingdom

1417 | A 1.2 kV 100 kW Four-Level ANPC Inverter with SiC Power Modules and Capacitor Voltage Balance for EV Traction Applications
Jun Wang, Ian Laird, Xibo Yuan, Wenzhi Zhou
University of Bristol, United Kingdom
**Technical Program**

2212 | **BEV Range Improvement Using Highly Efficient Downsized DC-DC Converter**  
Lei Hao¹, Chandra Namuduri¹, Chengwu Duan², Suresh Gopalakrishnan¹, Norman Bucknor¹  
¹General Motors, United States; ²General Motors, China

1704 | **Iron Losses Impact on High-Speed Drives**  
Emilio Carfagna¹, Emilio Lorenzani¹, Karthik Debbadi², Sante Pugliese², Marco Liserre²  
¹University of Modena and Reggio Emilia, Italy; ²Christian-Albrechts-Universität zu Kiel, Germany

1268 | **Integration and Cooling Strategies for WBG-Based Current-Source Inverters-Based Motor Drives**  
Woongkul Lee, Renato A. Torres, Hang Dai, Thomas M. Jahns, Bulent Sarlioglu  
University of Wisconsin Madison, United States

### Topic I: Power Semiconductor Devices

#### Session I01: Power Module and Integration – In Memory of Prof. Braham Ferreira

2538 | **EMI Propagation Path Modeling of 3-Level T-Type NPC Power Module with Stacked DBC Enabled EMI Shielding**  
Asif Imran Emon¹, Mustafeez Ul Hassan¹, Abdul Basit Mirza¹, Zhao Yuan², Fang Luo¹  
¹Stony Brook University, United States; ²University of Arkansas, United States

1367 | **Design and Analysis of a PCB-Embedded 1.2 kV SiC Half-Bridge Module**  
Jack Knoll¹, Gibong Son¹, Christina DiMarino¹, Qiang Li¹, Hannes Stahr², Mike Morianz²  
¹Virginia Polytechnic Institute and State University, United States; ²Austria Technologie & Systemtechnik AG, Austria

2117 | **Design, Fabrication, and Testing of a 1.7 kV SiC Switching Cell for a High-Density Integrated Power Electronics Building Block (iPEBB)**  
Narayanan Rajagopal¹, Christina DiMarino¹, Rolando Burgos¹, Taha Moaz¹, Igor Cvetkovic¹,  
Dushan Boroyevich¹, Olivier Mathieu²  
¹Virginia Polytechnic Institute and State University, United States; ²Rogers Corporation, Germany

2398 | **Layout, Packaging, and Efficiency Implications of a 1.7 kV Hybrid Si/SiC Reverse Blocking Switch Module in Soft-Switching Current Source Converters**  
Aniruddh Marellapudi, Bradford Houska, Mickael J. Mauger, Prasad Kandula, Deepak Divan  
Georgia Institute of Technology, United States

1377 | **A Novel SiC MOSFET Module for High-Power Soft-Switching Converter**  
Xiaolei Luo, Min Chen  
Zhejiang University, China

1960 | **Paralleling of Four 650V/60A GaN HEMTs for High Power Traction Drive Applications**  
Partha Pratim Das, Subhansu Satpathy, Suyash Sushilkumar Shah, Subhashish Bhattacharya, Victor Veliadis  
North Carolina State University, United States
Session I02: WBG and UWBG Devices

2503 | High Voltage Output Characteristics and Short Circuit Robustness of HV SiC MOSFETs
Ashish Kumar, Raj Kokkonda Kumar, Subhashish Bhattacharya, Jayant Baliga, Victor Veliadis
North Carolina State University, United States

1744 | 3.3 kV SiC JBS Diodes Employing a P2O5 Surface Passivation Treatment to Improve Electrical Characteristics
Arne Benjamin Renz1, Oliver James Vavasour1, Vishal Ajit Shah1, Vasantha Pathirana2, Tanya Trajkovic2, Yeganeh Bonyadi1, Ruizhu Wu1, Jose Angel Ortiz-Gonzalez1, Xiaoyun Rong1, Guy William Clarke Baker1, Philip Mawby1, Peter Michael Gammon1
1University of Warwick, United Kingdom; 2Cambridge Microelectronics Ltd., United Kingdom

2406 | Static and Dynamic Characterization of 650 V GaN E-HEMTs in Room and Cryogenic Environments
Mahmoud Mehrabankhomartash1, Shiyuan Yin1, Alfonso J. Cruz1, Lukas Graber1, Maryam Saeedifard1, Simon Evans2, Florian Kapaun3, Ivan Revel2, Gerhard Steiner3, Ludovic Ybanez2, Chanyeop Park4
1Georgia Institute of Technology, United States; 2Airbus, France; 3Airbus, Germany; 4Mississippi State University, United States

1827 | Performance Evaluation of Future T-Type PFC Rectifier and Inverter Systems with Monolithic Bidirectional 600V GaN Switches
F. Vollmaier1, N. Nain2, J. Huber2, J.W. Kolar2, K.K. Leong3, B. Pandya3
1Silicon Austria Labs GmbH, Austria; 2ETH Zürich, Switzerland; 3Infineon Technologies AG, Austria

1350 | Performance Evaluation of 650 V SiC MOSFET under Low Temperature Operation
Yuqi Wei, Md Maksudul Hossain, Xia Du, Rosten Sweeting, Alan Mantooth
University of Arkansas, United States

1432 | Active-Device Losses in Resonant Power Converters: A Case Study with Class-E Inverters
Nirmana Perera, Remco van Erp, Jessy Ançay, Armin Jafari, Elison Matioli
École Polytechnique Fédérale de Lausanne, Switzerland

Session I03: Passive Components

2269 | Permeability Engineered Soft Magnetics for Power Dense Energy Conversion
Kevin Byerly1, Satoru Simizu1, Michael E. McHenry1, Paul R. Ohodnicki2, R. Byron Beddingfield3, Subhashish Bhattacharya4, Geraldo Nojima4
1Carnegie Mellon University, United States; 2University of Pittsburgh, United States; 3North Carolina State University, United States; 4Eaton, United States

2409 | Characterization of Inductor Magnetic Cores for Cryogenic Applications
Shiyuan Yin1, Mahmoud Mehrabankhomartash1, Alfonso J. Cruz1, Lukas Graber1, Maryam Saeedifard1, Simon Evans2, Florian Kapaun3, Ivan Revel2, Gerhard Steiner3, Ludovic Ybanez2, Chanyeop Park4
1Georgia Institute of Technology, United States; 2Airbus, France; 3Airbus, Germany; 4Mississippi State University, United States

1369 | A Novel Measurement Method for DC Superimposition Characteristics of Three-Phase Coupled Inductors with Powder Cores
Yamato Mishima1, Tatsuya Aoki1, Kazuya Matsuta1, Jun Imaoka1, Masayoshi Yamamoto1, Kosuke Yoshimoto2
1Nagoya University, Japan; 2Daido Steel Co., Ltd., Japan

1638 | Condition Monitoring for Capacitors in Modular Multilevel Converter Based on High-Frequency Transient Analysis
Hongjian Xia1, Yi Zhang2, Huai Wang2, Minyou Chen1, Wei Lai1, Dan Luo1, Yulong Hu1
1Chongqing University, China; 2Aalborg University, Denmark
Session I04: Gate Drivers – 1

1293 | A Low Level-Clamped Active Gate Driver for Crosstalk Suppression of SiC MOSFET Based on dv/dt Detection
Hong Li, Zhidong Qiu, Tiancong Shao, Yangbin Zeng, Haitao Du, Chengdong Yin
Beijing Jiaotong University, China

1113 | Investigations on Online Junction Temperature Measurement for SiC-MOSFETs Using the Gate-Signal Injection Method
Johannes Ruthardt, David Hirning, Kanuj Sharma, Maximilian Nitzsche, Philipp Ziegler, Manuel Fischer, Jörg Roth-Stielow
University of Stuttgart, Germany

1806 | A High-Efficiency Charge-Pump Gate Drive Power Delivery Technique for Flying Capacitor Multi-Level Converters with Wide Operating Range
Rahul K. Iyer, Nathan M. Ellis, Zichao Ye, Robert C.N. Pilawa-Podgurski
University of California Berkeley, United States

2541 | Noise Immune Cascaded Gate Driver Solution for Driving High Speed GaN Power Devices
Abdul Basit Mirza, Asif Imran Emon, Sama Salehi Vala, Fang Luo
Stony Brook University, United States

Session I05: Gate Drivers – 2

2240 | A Closed-Loop Current Source Gate Driver with Active Voltage Balancing Control for Series-Connected GaN HEMTs
Zhengda Zhang, Chunhui Liu, Yunpeng Si, Yifu Liu, Mengzhi Wang, Qin Lei
Arizona State University, United States

2498 | Design and Selection of Optimal Inductor for Current Source Gate Drivers
Rajat Shahane, Satish Belkhode, Anshuman Shukla
Indian Institute of Technology Bombay, India

1941 | Gate Driver for 10 kV SiC MOSFET Power Module with High-Speed Current Sensing
Mark Cairnie, Christina DiMarino
Virginia Polytechnic Institute and State University, United States

1881 | Active Control and Gate-Driver Design for Voltage Balancing of Both MOSFETs and Body-Diodes in Series-Connected SiC MOSFETs
Xiang Lin, Lakshmi Ravi, Dong Dong, Rolando Burgos
Virginia Polytechnic Institute and State University, United States

1225 | Balancing the Switching Losses of Paralleled SiC MOSFETs Using a Stepwise Gate Driver
Christoph Lüdecke, Alireza Aghdaei, Michael Laumen, Rik W. De Doncker
RWTH Aachen University, Germany

1547 | An Active Gate Driver for Dynamic Current Sharing of Paralleled SiC MOSFETs
Xun Wang¹, Yang He¹, Junming Zhang¹, Shuai Shao¹, Han Li², Cheng Luo²
¹Zhejiang University, China; ²Eaton, China
Session I06: Gate Drivers – 3

2118 | Digital Gate Driving (DGD) is Double-Edged Sword: How to Avoid Huge Voltage Overshoots Caused by DGD for GaN FETs
Ryunosuke Katada¹, Katsuhiro Hata¹, Yoshitaka Yamauchi¹, Ting-Wei Wang¹², Ryuzo Morikawa¹, Cheng-Hsuan Wu¹, Toru Sai¹, Po-Hung Chen², Makoto Takamiya¹
¹The University of Tokyo, Japan; ²National Chiao Tung University, Taiwan

1154 | A 1ns-Resolution Load Adaptive Digital Gate Driver IC with Integrated 500ksps ADC for Drive Pattern Selection and Functional Safety Targeting Dependable SiC Applications
Shusuke Kawai, Takeshi Ueno, Hiroaki Ishihara, Satoshi Takaya, Koutaro Miyazaki, Kohei Onizuka Toshiba Corporation, Japan

2040 | An Intelligent Gate Driver with Self-Diagnosis and Prognosis for SiC MOSFETs
Sanghun Kim, Dongwoo Han, Xiaofeng Dong, Hui Li, Jinyeong Moon, Yuan Li, Fang Z. Peng Florida State University, United States

2091 | Comparison of Gate-Drive Switching Control for GaN HEMT Power Devices
Patrick Palmer¹, Edward Shelton², Mohammad Miri¹, Carissa King¹, Dan Rogers²
¹Simon Fraser University, Canada; ²University of Oxford, United Kingdom

2395 | A Trajectory Control Gate Driver for Wide Band Gap Devices in Standard Packages
Julien Morand, Julio Brandelero Mitsubishi Electric R&D Centre Europe, France

2156 | Gate-Source Voltage Analysis for Switching Crosstalk Evaluation in SiC MOSFETs Half-Bridge Converters
Luciano Salvo¹, Mario Pulvirenti¹, Angelo Giuseppe Sciacca¹, Giacomo Scelba², Mario Cacciato²
¹STMicroelectronics, Italy; ²University of Catania, Italy

Session I07: Magnetics – 1

1476 | A Novel Magnetic Integrated Unit for a Full-Soft-Switching Full-Bridge Converter
Cheng Deng¹, Li Tan¹, Andrés Escobar-Mejía²
¹Xiangtan University, China; ²Universidad Tecnológica de Pereira, Colombia

2239 | Symmetric Four-Phase Inverse Coupled Inductors for GaN-Based Interleaving Four-Phase Point-of-Load Converters
Longyang Yu¹, Wei Mu¹, Chengzi Yang¹, Lei Zhu¹, Zhiyuan Qi¹, Laili Wang¹, Yilong Yao¹, Yuquan Su², Chi Zhang²
¹Xi’an Jiaotong University, China; ²MiSiliconn Semiconductor Technologies Co., Ltd., China

1414 | A Novel PCB-Embedded Coupled Inductor Structure for Integrated Voltage Regulator
Feiyang Zhu, Qiang Li, Fred C. Lee Virginia Polytechnic Institute and State University, United States

2416 | An Integrated Magnetic Structure for Bi-Directional Two-Channel Interleaved Boost Converter with Coupled Inductor
Abdul Basit Mirza, Asif Imran Emon, Sama Salehi Vala, Fang Luo Stony Brook University, United States

1481 | A Passive Integrated Unit for Parallel-Resonant Isolated Bidirectional DC-DC Converter
Cheng Deng¹, Zhou You¹, Andrés Escobar-Mejía²
¹Xiangtan University, China; ²Universidad Tecnológica de Pereira, Colombia

1477 | A Passive Integration Unit for Electronic Ballast with Multiresonant Converter
Cheng Deng¹, Zhilin Zhou¹, Andrés Escobar-Mejía²
¹Xiangtan University, China; ²Universidad Tecnológica de Pereira, Colombia
Session I08: Magnetics – 2

1412 | An Accurate Analytical Model to Evaluate the Winding Loss of a Single-Layer Multi-Turn Planar Air-Core PCB-Inductor
Mingdong Wu, Li Wang, Daniyal Ahmed, Meng Peng, Ling Mao
Nanjing University of Aeronautics and Astronautics, China

1974 | Dimensional Effects of Core Loss and Design Considerations for High Frequency Magnetics
Ahmed Nabih, Rimon Gadelrab, Qiang Li, Fred C. Lee
Virginia Polytechnic Institute and State University, United States

1569 | An Integrated Planar Inductor Based on a Novel Magnetic Core Structure
Shuting Feng, Yongmei Gan, Longyang Yu, Huaqing Li, Chaojie Li, Wei Mu
Xi’an Jiaotong University, China

1100 | A Simple and Accurate Leakage Inductance Adjustment Method for Medium Frequency Transformer
Xuan Guo, Chi Li, Zedong Zheng, Yongdong Li
Tsinghua University, China

1416 | Modeling and Analysis of Multi-Phase Coupled Inductor Structures for Voltage Regulators
Feiyang Zhu, Qiang Li, Fred C. Lee
Virginia Polytechnic Institute and State University, United States

Session I09: Magnetics – 3

2221 | Laminated Permanent Magnets Enable Compact Magnetic Components in Current Source Converters
Xiangyu Han, Zheng An, Mickael J. Mauger, Joseph Benzaquen, Rajendra Prasad Kandula, Deepak Divan
Georgia Institute of Technology, United States

2453 | Analysis and Suppression of Corner Electrical Field in Magnetic Flux Valve
Junwei Cui, Chao Jia, Liyan Qu, Wei Qiao
University of Nebraska Lincoln, United States

1203 | Compact Design of a Wide Bandwidth High Current Sensor Using Tilted Magnetic Field Sensors
Philipp Ziegler, Yiru Zhao, Jörg Haarer, Johannes Ruthardt, Manuel Fischer, Jörg Roth-Stielow
University of Stuttgart, Germany

1041 | Controlled Measurement Setup to Characterize a Magnetic Material up into Deep Saturation
Jeremias Kaiser, Thomas Dürbaum
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

1616 | Design Methodology to Reduce the Lumped Winding Capacitance of Spiral Winding Transformer in LLC Converters
Mingde Zhou, Haoyu Wang, Dongdong Shu
ShanghaiTech University, China

2467 | A 700kHz 800V/14V GaN-Based DC-DC Converter with Optimized Integrated Transformer for Electrical Vehicles
Huu Phuc Kieu¹, Donghan Lee¹, Sewan Choi¹, Sangjin Kim²
¹Seoul National University of Science and Technology, Korea; ²Hyundai Motor Company, Korea
## Session I10: Application of Power Modules

### 1409 | Analytic Model of the Voltage Oscillation in a Power Conversion System with DC-Link Capacitors
Shuang Zhao, Wibawa Chou  
*Infineon Technologies AG, United States*

### 1062 | Lithium-Ion Capacitors: Charge Delivery Capability and Voltage Dependence of Capacitance
Hengzhao Yang  
*ShanghaiTech University, China*

### 2058 | Investigating the Effect of Multilevel Inverters on Motor Stator Insulation Stress
Arshiah Yusuf Mirza, Hiep Nguyen, Ali M. Bazzi, Yang Cao  
*University of Connecticut, United States*

### 1229 | Electret: A Solution to Partial Discharge in Power Electronics Applications
Farhina Haque, Omar Faruqe, Chanyeop Park  
*Mississippi State University, United States*

### 1713 | Linearly Scalable Cost-Efficient Parallel Method for High-Power Wide-Bandgap-Based Converters
Shang Gao, Zheyu Zhang  
*Clemson University, United States*

## Session I11: Semiconductor Devices

### 1635 | Commercialization of Diamond Semiconductor Devices
Manpuneet K. Benipal¹, Jesse Brown¹, Franz Koeck², Anna Zaniewski¹, Mohammad Faizan Ahmad¹, Robert Nemanich²  
¹Advent Diamond, Inc., United States; ²Arizona State University, United States

### 1544 | Analysis on Static Current Sharing of N-Paralleled Silicon Carbide MOSFETs
Yang He¹, Xun Wang¹, Junming Zhang¹, Shuai Shao¹, Han Li², Cheng Luo²  
¹Zhejiang University, China; ²Eaton, China

### 1837 | Junction-Temperature Sensing of Paralleled SiC MOSFETs Utilizing Temperature Sensitive Optical Parameters
Lukas A. Ruppert, Sven Kalker, Rik W. De Doncker  
RWTH Aachen University, Germany

### 2015 | Static and Dynamic Characteristics of SiC MOSFET under Extremely High Temperature
Xiaohui Lu, Laili Wang, Zaojun Ma, Qingshou Yang  
Xi’an Jiaotong University, China

### 1357 | Reverse Recovery Testing of Small-Signal Schottky Diodes
Weston D. Braun, Eric A. Stolt, Lei Gu, Juan M. Rivas-Davila  
Stanford University, United States

### 1431 | Analysis on Parasitic Capacitance to Prevent False Turn-On in GaN HEMT
Toshihiro Iwaki, Takashi Sawada, Jun Imaoka, Masayoshi Yamamoto  
Nagoya University, Japan

### 1586 | Dominant Model Parameter Extraction for Analyzing Current Imbalance in Parallel Connected SiC MOSFETs
Yohei Nakamura¹, Michihiro Shintani², Takashi Sato³  
¹ROHM Co., Ltd., Japan; ²Nara Institute of Science and Technology, Japan; ³Kyoto University, Japan
2051 | Circuit-Semiconductor Dynamic Coupling Analysis for PiN Diode Reverse Recovery  
Ruiwen Chen¹, Zhi Yang¹, Xiaoli Tian², Mingyang Wang¹, Yu Pan¹, Sideng Hu¹  
¹Zhejiang University, China; ²Chinese Academy of Sciences, China; ³Shanghai Institute of Space Power-Sources, China

Session II2: Thermal Management

1141 | Vascular Polymer Encapsulation for Integrated Thermal Management and Packaging of Electronics  
Anthony Coppola, Alireza Fatemi  
General Motors, United States

1903 | Directly Integrated Vapor Chamber as an Efficient Heat Spreader for High Heat Flux SiC MOSFET Dies in Power Modules  
Wei Mu¹, Binyu Wang¹, Shenghe Wang², Fengtao Yang¹, Dingkun Ma¹, Laili Wang¹  
¹Xian Jiaotong University, China; ²State Grid Anhui Electric Power Co., Ltd., China

1375 | Thermal Management Strategy for IGBT Modules in PV Systems Based on the Benefit-Cost Ratio  
Cheng Qian¹, Xiong Du¹, Rui Du¹, Jun Zhang²  
¹Chongqing University, China; ²Hohai University, China

1774 | Multiscale Electrothermal Design of a Modular Multilevel Converter for Grid-Tied Applications  
Xuhui Feng¹, Ramchandra Kotecha¹, Sreekant Narumanchi¹, Akanksha Singh¹, Barry Mather¹, Ke Wang², Boxue Hu², Jin Wang²  
¹National Renewable Energy Laboratory, United States; ²The Ohio State University, United States

1191 | Experimental Characterization of Frequency-Domain Thermal Impedance for Power Module under Different Boundary Conditions  
Leheng Wang, Mengqi Xu, Ke Ma  
Shanghai Jiao Tong University, China

1850 | Thermal Dissipation Approach Comparison and Evaluation for SiC Surface Mount Devices  
Victoria Baker¹, Boran Fan¹, Jack Knoll¹, Rolando Burgos¹, Warren Chen²  
¹Virginia Polytechnic Institute and State University, United States; ²Raytheon Technologies Research Center, United States

1696 | Influence Analysis of Thermally Conductive Epoxy Resin on the Electrical Design of a Compact AC/DC Converter  
Maximilian Nitzsche, Jörg Haarer, Julian Weimer, Dominik Koch, Jörg Roth-Stielow  
University of Stuttgart, Germany

Topic K: Emerging Technologies and Applications

Session K01: Wireless Power Transfer – 1

1400 | Analysis of a Wireless Power Transfer System with an Inverse Coupled Current Doubler Rectifier  
Lixin Shi, Alberto Delgado, Regina Ramos, Pedro Alou  
Universidad Politécnica de Madrid, Spain

2032 | Heuristic Algorithm-Based Design Method for Class-E Switching Circuits  
Wenqi Zhu, Yutaro Komiyama, Kien Nguyen, Hiroo Sekiya  
Chiba University, Japan
2351 | High Power, High Efficiency Wireless Power Transfer at 27.12 MHz Using CMCD Converters
Jack Rademacher, Xin Zan, Al Avestruz
University of Michigan, United States

1057 | Multi-Coil Constant Voltage Output Analysis Based on State Deconstruction for Wireless Power Transfer System
Sheng Liu, Yue Feng, Hao Chen, Jiande Wu, Xiangning He
Zhejiang University, China

Session K02: Measurements and Testing

1636 | Microchannel-Based Calorimeter for Rapid and Accurate Loss Measurements on High-Efficiency Power Converters
Remco van Erp, Nirmana Perera, Elison Matioli
École Polytechnique Fédérale de Lausanne, Switzerland

1314 | Design and Operation of a Medium Voltage Pulse Test Apparatus for Short-Circuit Testing of DC Solid State Circuit Breakers
Andy Schroedermeier, Andrew Rockhill
Eaton, United States

1552 | Gate Driver Design for 1.2 kV SiC Module with PCB Integrated Rogowski Coil Protection Circuit
Marco Stecca, Panagiotis Tiftikidis, Thiago Soeiro, Pavol Bauer
Delft University of Technology, The Netherlands

2382 | Thermal-HIL Real-Time Testing Platform for Evaluating Cooling Systems of Power Rectifiers
Carl Ngai Man Ho, Yin Fang, Yanming Xu, Isuru Jayawardana
University of Manitoba, Canada

Session K03: Emerging Technologies and Applications – 1

1420 | Efficiency Optimization of Wireless Power Transfer Systems Having Multiple Receivers with Cross-Coupling by Resonant Frequency Adjustment of Receivers
Arpan Laha, Abirami Kalathy, Praveen Jain
Queen’s University, Canada

1701 | A 27.12-MHz kV-Scale Power Amplifier with a Tunable Multistage Matching Network for a Compact Ion-Beam Accelerator
Yuetao Hou¹, Sreyam Sinha¹, Di Ni¹, Qing Ji², Arun Persaud², Peter Seidl², Thomas Schenkel², Amit Lal¹, Khurram K. Afridi¹
¹Cornell University, United States; ²Lawrence Berkeley National Laboratory, United States

2030 | Standing Wave Induced Field Focusing Transceiver for Wireless Capacitive Power Transfer
Tanner Mingen, Matthew Pearce, Tyler Marcrum, Charles Van Neste
Tennessee Tech University, United States

2466 | Energy Recovery Circuit for LC Cell Driver
Jacob Huff, Miao Wang, Mark J. Scott
Miami University, United States

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### Session K04: Wireless Power Transfer – 2

<table>
<thead>
<tr>
<th>Session</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1522</td>
<td>A Modular Multilevel Converter Based Inductive Power Transfer System</td>
<td>Wenwei Victor Wang, Feiyang Jackman Lin, Duleepa J. Thrimawithana, Grant Covic</td>
<td>University of Auckland, New Zealand</td>
</tr>
<tr>
<td>1758</td>
<td>Multiple-Transmitter with Phase-Shift and Dynamic ZVS Angle Controls at Fixed Operating Frequency for Cross-Interference Free Wireless Power Transfer Systems</td>
<td>Kodai Matsuura, Masataka Ishihara, Akihiro Konishi, Kazuhiro Umetani, Eiji Hiraki</td>
<td>Okayama University, Japan</td>
</tr>
<tr>
<td>2057</td>
<td>Roadway Embeddable Multi-MHz Capacitive Wireless Charging System with Matching Network Realized Using Wiring Parasitics</td>
<td>Sounak Maji, Sreyam Sinha, Khurram K. Afridi</td>
<td>Cornell University, United States</td>
</tr>
<tr>
<td>2390</td>
<td>A 13.56 MHz Bidirectional IPT System with Wirelessly Synchronised Transceivers for Ultra-Low Coupling Operation</td>
<td>Nunzio Pucci, Juan M. Arteaga, Christopher H. Kwan, David C. Yates, Paul D. Mitcheson</td>
<td>Imperial College London, United Kingdom</td>
</tr>
<tr>
<td>2318</td>
<td>Wireless Power Transfer System with Variable Mutual Inductance Control for Battery Charging</td>
<td>Federica Cammarata(^1), Santi Agatino Rizzo(^2), Giacomo Scelba(^3), Giuseppe Longo(^1), Filippo Scrimizzi(^1), Giuseppe Ballarin(^1)</td>
<td>1STMicroelectronics, Italy; 2University of Catania, Italy; 3Wurth Elektronik, Italy</td>
</tr>
<tr>
<td>2302</td>
<td>GaN-Based Wireless Charging System with Self-Driven Rectifier</td>
<td>Ruibang Li(^1), Chenxu Zhao(^1), Yongbin Jiang(^3), Min Wu(^1), Shuting Feng(^1), Laili Wang(^1), Yunqing Pei(^1), Hong Zhang(^1)</td>
<td>1Xi’an Jiaotong University, China; 2UNISOC (Shanghai) Technologies Co., Ltd., China</td>
</tr>
<tr>
<td>1012</td>
<td>Inverter Phase Current Balancing for Wireless Power Transfer Systems Based on Parallel Resonant Networks</td>
<td>Yiming Zhang(^1), Zhiwei Shen(^1), Xin Li(^2), Shuxin Chen(^2), Yi Tang(^2)</td>
<td>1Fuzhou University, China; 2Nanyang Technological University, Singapore</td>
</tr>
<tr>
<td>2210</td>
<td>Analysis of Wireless Power Transfer System Employing Active Shielding with Virtual Inductance and Two-Port Equivalent Circuit</td>
<td>Keita Furukawa, Keisuke Kusaka, Jun-ichi Itoh</td>
<td>Nagoya University of Technology, Japan</td>
</tr>
</tbody>
</table>

### Session K05: Wireless Power Transfer – 3

<table>
<thead>
<tr>
<th>Session</th>
<th>Title</th>
<th>Authors</th>
<th>Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>2047</td>
<td>A Variable Compensation Inverter Rectifier (VCIR) Based Approach to Compensate for Coupling Variations in Wireless Power Transfer Systems</td>
<td>Sreyam Sinha(^1), Ashish Kumar(^2), Khurram K. Afridi(^1)</td>
<td>1Cornell University, United States; 2Texas Instruments, United States</td>
</tr>
<tr>
<td>1938</td>
<td>Bidirectional Class E2 Resonant Converter in Wireless Power Transfer Systems</td>
<td>Minki Kim, Jungwon Choi</td>
<td>University of Minnesota Twin Cities, United States</td>
</tr>
<tr>
<td>1471</td>
<td>A Control Strategy for ZVS Realization in LCC-S Compensated WPT System with Semi Bridgeless Active Rectifier for Wireless EV Charging</td>
<td>Mingyang Li, Junjun Deng, Deliang Chen, Wenbo Wang, Zhenpo Wang, Yang Li</td>
<td>Beijing Institution of Technology, China</td>
</tr>
<tr>
<td>Session K06: Energy Harvesting</td>
<td></td>
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<td></td>
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<td></td>
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</tr>
</tbody>
</table>

### 1329 | A Dual-Resonance Electromagnetic Vibration Energy Harvester for Wide Harvested Frequency Range  
Zhijie Feng, Han Peng, Yong Chen, Jiahua Chen, Kangyi Sun  
Huazhong University of Science and Technology, China

### 1250 | A Single-Stage Dual-Mode AC-DC Converter for Vibration Energy Harvesting with Uninterrupted Output  
Jiayong Yuan, Han Peng, Hanyi Sun, Hongfei Xiao  
Huazhong University of Science and Technology, China

### 1659 | A Coil Connection Switching Strategy for Maximum Power Delivery in Electromagnetic Vibration Energy Harvesting System  
Hongfei Xiao, Han Peng, Jiayong Yuan  
Huazhong University of Science and Technology, China

### 1546 | A Self Start-Up Circuit in Low Voltage Power Conversions for Electromagnetic Energy Harvesting with Optimized Power Distributions  
Jiahua Chen¹, Han Peng¹, Zhijie Feng¹, Kai Gao², Shaojing Wang², Peng Xu²  
¹Huazhong University of Science and Technology, China; ²State Grid Shanghai Electric Power Research Institute, China

### 2450 | Performance Comparison of Burst-Mode MPPT and Perturb and Observe MPPT Algorithms for Photovoltaic Energy Harvesting Applications  
F. Selin Bagci, Katherine A. Kim  
National Taiwan University, Taiwan
## Session K07: Measurements and Testing

### 1224 | A Simple Measurement Method of Common Source Inductance for GaN Devices
Jiarui Wu¹, Xu Yang¹, Kangping Wang¹, Jiwen Wei¹, Zhiyuan Qi¹, Wenjie Chen¹, Qiaoliang Chen²
¹Xi’an Jiaotong University, China; ²Longteng Semiconductor Co., Ltd., China

### 1332 | Film Capacitors ESL Extraction Based on SiC MOSFET Switching Transient Process
Jianfeng Niu¹, Zejun He², Yun Lei³, Mingyang Wang¹, Jing Zhou¹, Sideng Hu¹
¹Zhejiang University, China; ²Ningbo Jiangbei Gofront Herong Electric Co., Ltd., China

### 1487 | GaN-Based ±5kV/100kHz PWM Generator for Advanced Partial Discharge Characterization
Zhicheng Guo, Tianxiang Chen, Ruiyang Yu, Alex Q. Huang
The University of Texas at Austin, United States

### 1380 | An Effective Impedance-Phase Method for Sensorless Measurement of Li-Ion Battery Cells’ Internal Temperature
Ala A. Hussein¹, Abbas A. Fardoun²
¹Prince Mohammad Bin Fahd University, Saudi Arabia; ²Al-Marref University, Lebanon

### 1381 | An Extended Kalman Filter with Exponential Thermoelectric Measurement Model for Sensorless Surface Temperature Estimation of Li-Ion Batteries
Mahroo Sajjad¹, Ali Wadi², Mamoun Abdel-Hafez³, Ala A. Hussein²
¹American University of Sharjah, United Arab Emirates; ²Prince Mohammad Bin Fahd University, Saudi Arabia

## Session K08: Emerging Technologies and Applications – 2

### 2559 | High-Performance Distributed Power Electronics Communication Network Design with 5 Gbps Data Rate and Sub-Nanosecond Synchronization Accuracy
Yu Rong¹, Zhiyu Shen², Boran Fan¹, Vladimir Mitrovic¹, Jianghui Yu¹, Slavko Mocevic¹, Jun Wang³, Dushan Boroyevich¹, Rolando Burgos¹
¹Virginia Polytechnic Institute and State University, United States; ²Delta Electronics (America) Ltd., United States; ³University of Nebraska Lincoln, United States

### 1105 | Analysis and Design of a Latching Current Limiter Based on a SiC N-MOSFET
Abraham López¹, Pablo F. Miaja¹, Manuel Arias¹, Arturo Fernández²
¹University of Oviedo, Spain; ²European Space Agency, The Netherlands

### 1898 | Design and Development of Modular Hybrid DC Breaker Scheme for DC Distribution Systems
D.K.J.S. Jayamaha¹, Ken K.M. Siu², Carl N.M. Ho¹, A.D. Rajapakse¹
¹University of Manitoba, Canada; ²University of North Texas, United States

### 2431 | High Density Power Converter Design for Pulsed NMR Applications
Yu Yao, Harish S. Krishnamoorthy
University of Houston, United States

### 1497 | Electrical Variable Capacitor of Reduced Switch Count and Voltage Stress for 13.56MHz RF Plasma System
Juhwa Min, Yongsug Suh
Jeonbuk National University, Korea

### 2109 | Parallel Operation of Gradient Power Amplifiers without Large Current-Sharing Reactor
Mingyu Xue, Haicong Zhang, Bin Cao, Xu Chu
Shanghai United-Imaging Healthcare Co., Ltd., China
Session K09: Emerging Technologies and Applications – 3

1441 | An Adjustable Stiffness Torsional Magnetic Spring with a Linear Stroke Length
Dawei Che¹, Jonathan Z. Bird¹, Alex Hagmuller², Md Emrad Hossain¹
¹Portland State University, United States; ²Aquaharmonics Inc., United States

1173 | Auto-Tuning Control of a Switched-Mode Power Converter for Tailored Pulse-Shape Biased Plasma Etching Applications
Qihao Yu, Erik Lemmen, Korneel Wijnands, Bas Vermulst
Eindhoven University of Technology, The Netherlands

2457 | Liquid Conductor Electric Machines: A New Cooling Approach for Pulsed Power Applications
Bryan Paul Ruddy¹, Yi Chen Mazumdar², Jason Yunhe Guan³
¹University of Auckland, New Zealand; ²Georgia Institute of Technology, United States; ³Fisher and Paykel Healthcare, New Zealand

1440 | Analysis and Experimental Testing of a New Type of Variable Stiffness Magnetic Spring with a Linear Stroke Length
Md Emrad Hossain, Jonathan Z. Bird, Victor Albarran, Dawei Che
Portland State University, United States

1530 | Harmonics Suppression Using a GaN-Based Flying-Capacitor Multilevel Inverter with PWM Operation at 13.6 MHz
Fiqih Tri Fathulah Rusfa, Hideaki Fujita
Tokyo Institute of Technology, Japan
Technical Session Chairs

A01 | Photovoltaic Systems
Mao Meiqin, Hefei University of Technology, China
Shangzhi Pan, Wuhan University, China

A02 | Renewable and Sustainable Energy Systems
Mao Meiqin, Hefei University of Technology, China
Shangzhi Pan, Wuhan University, China

A03 | Power Converters for Renewable and Sustainable Energy Systems
Subhashish Bhattacharya, North Carolina State University, USA

A04 | Control of Photovoltaic Systems
Yongheng Yang, Zhejiang University, China
Gabriele Rizzoli, University of Bologna, Italy

A05 | Energy Storage Systems
Hengzhao Yang, ShanghaiTech University, China

A06 | Microgrids and Grid Integration of Renewables
Weimin Wu, Shanghai Maritime University, China

A07 | Power Electronics for Renewable Energy Systems
Dao Zhou, Aalborg University, Denmark

A08 | Control of Renewable Energy Systems
Ali Khajehoddin, University of Alberta, Canada

A09 | Grid Integration of Renewables
Bhim Singh, Indian Institute of Technology Delhi, India

A10 | Wind Energy Systems
Ke Ma, Shanghai Jiao Tong University, China
Gabriele Rizzoli, University of Bologna, Italy

A11 | Other Topics in Renewables
Jae-Do Park, University of Colorado Denver, USA

A12 | Architectures for Renewable and Hybrid Renewable Energy Systems
Tiefu Zhao, The University of North Carolina at Charlotte, USA

A13 | Renewable Energy and Storage Systems
Alessandro Serpi, University of Cagliari, Italy

A14 | Applications for Renewable and Sustainable Energy Systems
Basu Kaushik, Indian Institute of Science, India

B01 | Power Converters for Distributed Resources and Microgrids
Hassan Mustafeez Ul, Stony Brook University, USA
Johannes Voss, RWTH Aachen University, Germany

B02 | V2G and G2V
David Lowther, McGill University, Canada

B03 | Control of DC Microgrids
Jae-Do Park, University of Colorado Denver, USA
Ngai Man Ho, University of Manitoba, Canada

B04 | Grid Intelligence for Unique Loading Scenarios
Homer Alan Mantooth, University of Arkansas, USA
Mehrdad Aghamohamadi, Flinders University, Australia

B05 | Power Converter Utilization in Microgrids
Fei Wang, The University of Tennessee, Knoxville, USA
Dong Cao, University of Dayton, USA

B06 | Smart Buildings and Energy Management Strategies
Dan Ionel, University of Kentucky, USA
Giri Venkataramanan, University of Wisconsin-Madison, USA

B07 | Stability and Power Quality
Yue Zhao, University of Arkansas, USA
Chao Wu, Aalborg University, Denmark
Technical Session Chairs

**B08 | Control of Distributed Resources and Microgrids**
Pablo Garcia Fernandez, University of Oviedo, Spain  
Joseph Pou, Nanyang Technological University, Singapore

**B09 | Control of Renewable Energy Resources**
Wei Qiao, University of Nebraska-Lincoln, USA  
Kai Sun, Tsinghua University, China

**B10 | Control of Grid-Tied Inverters**
Vikram Roy Chowdhury, Georgia Institute of Technology, USA  
Xibo Yuan, The University of Bristol, UK

**B11 | Control of DC Microgrids**
Subhashish Bhattacharya, North Carolina State University, USA  
Luis Herrera, University at Buffalo, USA

**B12 | Microgrid Control**
Jing Wang, NREL, USA  
Carlos Gomez-Aleixandre, University of Oviedo, Spain

**B13 | Solid State Transformers**
Robert Cuzner, University of Wisconsin-Milwaukee, USA  
Harish Krishnamoorthy, University of Houston, USA

**B14 | Power Converters for Distributed Resources and Microgrids**
Victor Veliadis, PowerAmerica, North Carolina State University, USA  
Asier Garcia-Bediaga, IKERLAN S COOP, Spain

**B15 | High Power, Power Electronic Systems for Utility Applications**
Eduard Muljadi, Auburn University, USA  
Jingyang Fang, TU Kaiserslautern, Germany

**B16 | Hybrid Transformers**
Joseph Benzaquen, Georgia Institute of Technology, USA  
Shahab Mehraeen, Louisiana State University, USA

**C01 | Big Data, Machine Learning, Cyber Security**
Kevin Hermanns, PE Systems, Germany  
Minjie Chen, Princeton University, USA  
Subham Sahoo, Aalborg University, Denmark

**C02 | Artificial Intelligence and Machine Learning**
Kevin Hermanns, PE Systems, Germany  
Minjie Chen, Princeton University, USA  
Subham Sahoo, Aalborg University, Denmark

**C03 | Other Topics in Big Data, Machine Learning, Cyber Security and Design Automation**
Kevin Hermanns, PE Systems, Germany  
Minjie Chen, Princeton University, USA  
Subham Sahoo, Aalborg University, Denmark

**C04 | Data Analysis for Batteries and Energy Storage**
Kevin Hermanns, PE Systems, Germany  
Minjie Chen, Princeton University, USA  
Subham Sahoo, Aalborg University, Denmark

**C05 | Cyber Security and Cyber Attacks**
Kevin Hermanns, PE Systems, Germany  
Minjie Chen, Princeton University, USA  
Subham Sahoo, Aalborg University, Denmark

**D01 | Electric Drivetrains**
Matt Lee, Michigan State University, USA

**D02 | Battery Management Systems for Transportation**
Subrata Saha, Aisin Corporation

**D03 | Charging Techniques for Transportation**
Peng Han, Ansys, Inc.

**D04 | Transportation Electrification – 1**
Ali Bazza, University of Connecticut, USA

**D05 | Transportation Electrification – 2**
Jiang Biao He, University of Kentucky, USA

**D06 | Transportation Electrification – 3**
Md. Sariful Islam, Halla Mechatronics

**D07 | Electric Vehicle Charging**
Bulent Sarlioglu, University of Wisconsin-Madison, USA

**D08 | EV Battery Management – 1**
Ozge Taskin, Ricardo UK Ltd
Technical Session Chairs

**D09 | EV Battery Management – 2**
Renato Amorim Torres, University of Wisconsin - Madison, USA

**E01 | DC-DC Non-Isolated – 1**
Olivier Trescases, University of Toronto, Canada

**E02 | DC-DC Isolated – 1**
Yilmaz Sozer, University of Akron, USA

**E03 | DC-DC Isolated – 2**
Ali Khajehoddin, University of Alberta, USA

**E04 | AC-DC Single Phase Converters – 1**
Iustin Radu Bojoi, Politecnico di Torino, Italy

**E05 | AC-DC & DC-AC Topologies & Control**
Luca Tarisciotti, University Andres Bello, Chile

**E06 | DC-AC Multiphase Converters**
Ali Bazzi, University of Connecticut, USA

**E07 | Multilevel Converters – In Memory of Prof. Akira Nabae**
Hirofuma Akagi, Tokyo Institute of Technology, Japan
Fang Z. Peng, Florida State University, USA

**E08 | DC-DC Non-Isolated – 2**
Santanu K. Mishra, Indian Institute of Technology

**E09 | DC-DC Non-Isolated – 3**
Fang Luo, Stony Brook University, New York, USA

**E10 | DC-DC Isolated – 3**
Qiang Li, Center for Power Electronics Systems, Virginia Tech, USA

**E11 | DC-DC Isolated – 4**
Paolo Mattavelli, University of Padova, Italy

**E12 | DC-DC Isolated – 5**
Hengzhou Yang, Shanghai Tech University, China

**E13 | DC-DC Isolated – 6**
Maohang Qiu, University of Dayton, USA

**E14 | AC-DC Single Phase Converters – 2**
Concettina Buccella, University of L’Aquila, Italy

**E15 | AC-DC Single Phase Converters – 3**
Jee-Hoon Jung, Ulsan National Institute of Science and Technology, South Korea

**E16 | AC-DC MultiPhase Converters – 11**
Mahshid Amirabadi, Northeastern University, USA

**E17 | DC-AC Single Phase Converter – 1**
Jiangbiao He, University of Kentucky, USA

**E18 | DC-AC Single Phase Converter – 2**
Xibo Yuan, The University of Bristol, UK

**E19 | AC-AC Isolated**
Damian Summers-Oselebo, Naval Sea Systems Command (NAVSEA), USA

**E20 | Multilevel Converters – Topologies – 1**
Seung-Ki Sul, Seoul National University

**E21 | Multilevel Converters – Topologies – 2**
Marco Di Benedetto, Roma Tre University, Italy

**E22 | Multilevel Converters – Topologies – 3**
Mahima Gupta, Portland State University, USA

**E23 | Multilevel Converters – Control – 1**
Roberto Petrella, University of Udine, Italy

**E24 | Multilevel Converters – Control – 2**
Subhashish Bhattacharya, NC State University, USA

**E25 | DC-AC Multi-Phase Converters – 2**
Riccardo Leuzzi, University of Pavia, Italy

**F01 | Dynamic Modeling of Power Converters**
Alex Hanson, University of Texas at Austin, USA

**F02 | Reliability, Diagnostics and Fault Analysis of Power Converters**
Meng Huang, Wuhan University, China

**F03 | Control of DC-DC converters**
Carl Ho, University of Manitoba, Canada

**F04 | Power Converter Modeling and Control**
Yuhua Du, Temple University, USA
Technical Session Chairs

F05 | Power Converter Stability
Yuhua Du, Temple University, USA

F06 | Power Converter EMI
Hang Dai, University of Wisconsin-Madison, USA

F07 | Converter Power Quality
Shuang Zhao, Infineon Technologies

F08 | Design and Control of Power Converters
Jungwon Choi, University of Minnesota, USA

F09 | Power Converter Stability and Control
Yuhua Du, Temple University, USA

F10 | Control Aspects of Grid-connected Converters
Petros Karamanakos, Tampere University, USA

F11 | Power Converter Control
Petros Karamanakos, Tampere University, USA

F12 | Dynamic Modeling of Power Converters
Jungwon Choi, University of Minnesota, USA

F13 | Modulation of Power Converters
Kevin Bai, The University of Tennessee, USA

F14 | Design and Control of Power Converters I
Alex Hanson, University of Texas at Austin, USA

F15 | Utility Applications of Power Electronics
Jun Wang, University of Nebraska-Lincoln, USA

F16 | Other Topics in Design, Control, Modelling and Optimization of Power Converters
Helen Cui, The University of Tennessee, USA

F17 | Power Converter Modeling and Control – 1
Xiaonan Lu, Temple University, USA

F18 | Power Converter Modeling and Control – 2
Tianqi Hong, Argonne National Laboratory, USA

F19 | Power Converter Modeling and Control – 3
Tianqi Hong, Argonne National Laboratory, USA

F20 | Power Converter Modeling and Control – 4
Yuhua Du, Temple University, USA

F21 | Power Converter Stability I
Tianqi Hong, Argonne National Laboratory, USA

F22 | Control Aspects in Power Electronic Systems – 1
Jianzhe Liu, Argonne National Laboratory, USA

F23 | Control Aspects in Power Electronic Systems – 2
Jianzhe Liu, Argonne National Laboratory, USA

F24 | Control Aspects in Power Electronic Systems – 3
Li Zhang, Nanyang Technological University, Singapore

F25 | Modeling and Control in Power Electronic Systems
Jun Wang, University of Nebraska-Lincoln, USA

F26 | Power Converter EMI I
Hang Dai, University of Wisconsin-Madison, USA

F27 | Converter Power Quality I
Zhiwei Zhang, The Ohio State University, USA

F28 | Reliability, Diagnostics and Fault Analysis of Power Converters – 1
Omer Gundogmus, GE Global Research Center

F29 | Reliability, Diagnostics and Fault Analysis of Power Converters – 2
Omer Gundogmus, GE Global Research Center

G01 | Electric Machines in Transportation
Nick Simpson, University of Bristol, UK

G02 | Permanent Magnet Machines – 1
Silvio Vaschetto, Politecnico di Torino, Italy

G03 | Modeling of Electric Machines – 1
Alessandro Serpi, University of Cagliari, Italy

G04 | Permanent Magnet Machines – 2
Eric Severson, University of Wisconsin-Madison, USA

G05 | Electric Machines: Fault Analysis
Jose Antonino-Daviu, Technical University of Valencia, Spain
Technical Session Chairs

G06 | Thermal Analysis of Electric Machines
Silvio Vaschetto, Politecnico di Torino, Italy

G07 | Electric Machines Materials and Additive Manufacturing
Shanelle Foster, Michigan State University, USA

G08 | Loss Analysis in Electric Machines
Nick Simpson, University of Bristol, UK

G09 | Noise and Vibration in Electric Machines
Jose Antonio-Daviu, Technical University of Valencia, Spain

G10 | High Speed and Bearingless Machines
Eric Severson, University of Wisconsin-Madison, USA

G11 | Electrical Machines – 1
Alessandro Serpi, University of Cagliari, Italy

G12 | Electrical Machines – 2
Andrea Cavagnino, Politecnico di Torino, Italy

G13 | Electrical Machines – 3
Gerd Bramerdorfer, JKU Linz, Austria

G14 | Modeling of Electric Machines – 2
Gerd Bramerdorfer, JKU Linz, Austria

G15 | IPMSM and Synchronous Reluctance Machines
Prerit Pramod, Nexteer Automotive, USA

G16 | Other Synchronous Machines – 1
Prerit Pramod, Nexteer Automotive, USA

G17 | Other Synchronous Machines – 2
Andrea Cavagnino, Politecnico di Torino, Italy

G18 | Switched reluctance and flux switching machines
Giulio De Donato, University of Roma La Sapienza, Italy

G19 | Actuators, Axial Flux and Linear Machines
Giulio De Donato, University of Roma La Sapienza, Italy

G20 | Electrical Machines – 4
Rukmi Dutta, University of New South Wales, Australia

G21 | Noise and Vibration in Electric Machines – 2
David Reigosa, University of Oviedo, Spain

G22 | Modeling of Electric Machines – 3
Greg Heins, Regal Beloit, Australia

G23 | High Speed Machines – 1
Rajesh Deodhar, IMRA Europe SAS, UK

G24 | Electrical Machines – 5
Rukmi Dutta, University of New South Wales, Australia

G25 | High Speed Machines – 2
Greg Heins, Regal Beloit, Australia

H01 | PM Motor Drives – 1
Peng Han, Ansys, Inc.

H02 | Control for Electric Drives
Roberto Petrella, University of Udine, Italy

H03 | New Technologies, Sensors, Reliability and Testing
Jul-Ki Seok, Yeungnam University, Korea

H04 | Sensorless Control of Electric Drives – 1
Yang Xu, Ford Motor Company

H05 | Sensorless Control of Electric Drives – 2
Roberto Petrella, University of Udine, Italy

H06 | Electric Drive Switching
Mahesh Swamy, Milwaukee Tool, USA

H07 | PM Motor Drives – 2
Paolo Pescetto, Politecnico Di Torino, Italy

H08 | Electric Drives
Pinjia Zhang, Tsinghua University, China

H09 | Induction Motor Drives
Pan Di, GE Global Research

H10 | PM Motor Drives – 1
Luca Zarri, University of Bologna, Italy
H11 | Control of Electric Drives – 1
Yang Xu, Ford Motor Company

H12 | Control of Electric Drives – 2
Paolo Pescetto, Politecnico Di Torino, Italy

H13 | Sensorless Control of Drives
Peng Han, Ansys, Inc.

H14 | Diagnostics, Fault Tolerance and Reliability in Electric Drives
Giacomo Scelba, University of Catania, Italy

H15 | Medium Voltage and Drive Applications
Kevin Lee, Eaton Corp.

H16 | Electric Drive Applications
Giacomo Scelba, University of Catania, Italy

I01 | Power Module and Integration – In Memory of Bram Ferreira
Adam Skorek, Université du Québec à Trois Rivières, Canada

I02 | WBG and UWBG Devices
Jose Ortiz Gonzalez, University of Warwick, UK

I03 | Passive Components
Hengzhao Yang, ShanghaiTech University, China

I04 | Gate Drivers – 1
Tanya Gachovska, Solantro Semiconductors Corp.

I05 | Gate Drivers – 2
Zheyu Zhang, Clemson University, USA

I06 | Gate Drivers – 3
Patrick Palmer, Simon Fraser University, Canada

I07 | Magnetics – 1
Shuo Wang, University of Florida, USA

I08 | Magnetics – 2
Shuo Wang, University of Florida, USA

I09 | Magnetics – 3
Christina DiMarino, Center for Power Electronics Systems, Virginia Tech, USA

I10 | Application of Power Modules
Yarui Peng, University of Arkansas, USA

I11 | Semiconductor Devices
Francesco Iannuzzo, Aalborg University, Denmark

I12 | Thermal Management
Adam Skorek, Université du Québec à Trois Rivières, Canada

K01 | Wireless Power Transfer – 1
Mehdi Narimani, McMaster University, Canada

K02 | Measurements and Testing
Ariya Sangwongwanich, Aalborg University, Denmark

K03 | Emerging Technologies and Applications – 1
Huai Wang, Aalborg University, Denmark

K04 | Wireless Power Transfer – 2
Mahshid Amirabadi, Northeastern University, USA

K05 | Wireless Power Transfer – 3
Prasad Rajendra Kandula, Georgia Institute of Technology, USA

K06 | Energy Harvesting
Huai Wang, Aalborg University, Denmark

K07 | Measurements and Testing
Ariya Sangwongwanich, Aalborg University, Denmark

K08 | Emerging Technologies and Applications – 2
Harish Sarma Krishnamoorthy, University of Houston, USA

K09 | Emerging Technologies and Applications – 3
Harish Sarma Krishnamoorthy, University of Houston, USA
Product Sessions

These half-hour, industry-driven sessions, provide an in-depth look off the show floor from our exhibitors, showcasing their innovative products and services.

8:30AM-9:00 AM


This Hardware-in-the-Loop demo consists of an inverter controller for grid-connected solar energies and an OP4510 real-time simulator. The controller, developed by the GREENLAB of Hefei University of Technology, is capable of low-voltage ride through—while the Electric Hardware Solver (eHS) is running on the OP4510, and simulates the entire grid-connected solar-energy inverter in real-time on the FPGA at a time step of less than 250 nanoseconds. The design of circuit schematic is done using the new OPAL-RT Schematic Editor. The model receives the PWM gating signals from external controller via digital inputs, and feeds the voltage and current measurement to controller via analog outputs. Also, the HIL model can perform soft-start, soft-stop or soft-reset, as well as update the PID parameters of the external controller via RS232 protocol. Therefore, users can conduct numerous tests automatically using API scripts. Particularly, the scenario features allows the user to pre-define different levels of voltage-sag or the short-circuit level of the host grid for the requirement of low voltage ride through (LVDT) tests.

9:00AM-9:30 AM

Evolution of Power Delivery for Cloud Computing

New architectures and technologies are increasing power density and efficiency reducing TCO (Total Cost of Ownership.) From AC-DC to the Point of Load, we will look at the power delivery topologies leveraging ST’s unique portfolio, the most complete in the market, with the latest innovations in GaN transistors and drivers.

3:30PM-4:00PM

G3R™ SiC MOSFETs, Unparalleled Performance and Robustness

High-efficiency energy usage has become a critical deliverable in next-generation power converters and silicon carbide (SiC) power devices continue to be the key components driving this revolution. In this session, GeneSiC will discuss the superiority of its third-generation (G3R™) SiC MOSFETs, including the performance advantages, design considerations as well as the importance of quality and reliability in demanding applications.
Student Demonstrations

Student Demonstrations provide an opportunity for students from various universities and countries to showcase their emerging technology research outcomes and interact with academia and industry.

Hardware Competition

High Power Density GaN-Based Online Uninterruptible Power Supply
Maida Farooq, Danish Shahzad, Prof. Khurram Afridi
Cornell University, USA

High Power Density GaN-Based Online Uninterruptible Power Supply
Mausamjeet Khatua, Prof. Khurram Afridi
Cornell University, USA

Demonstration of Power Sink with Wide Power-Bandwidth to Emulate Residential Loads
Hitesh Kumar, Prof. Santanu K. Mishra
Indian Institute of Technology Kanpur, India

Common Mode EMI Analysis in Power Electronics Enabled Power System
Ashik Amin, Tahmid Ibne Mannan, Prof. Seunghdeo Choi
Mississippi State University, USA

Machine Learning Methods and Open-Source Database for Magnetic Core Loss Modeling
Haoran Li, Mian Liao, Shukai Wang, Prof. Minjie Chen
Princeton University, USA

Vertical-Stacked Liquid-Cooled 48 V-1 V CPU Voltage Regulator with Extreme Power Density
Youssef Elasser, Ping Wang, Prof. Minjie Chen, Dr. Jael Baek
Princeton University, USA

A 700kHz 800V/14V GaN-based Isolated DC-DC Converter with Optimized Integrated Transformer for Electrical Vehicles
Huu Phuc Kieu, Donghan Lee, Prof. Sewan Choi
Seoul National University of Science and Technology, South Korea

Blockchain-Enabled Security Module for Firmware Security-Enhanced Smart Inverter
BoHyun Ahn, Seerin Ahmad, Swathi Pedavalli, Prof. Taesic Kim
Texas A&M University-Kingsville, USA

PowerSynth an MCPMs layout Optimization Tool
Quang Le, Imam Al Razi, Tristan Evans, Prof. Alan Mantooth, Prof. Yarui Peng
University of Arkansas, USA

Active Life Balancing to Condition Li-ion Battery Packs
Marium Rasheed, Prof. Regan Zane
Utah State University, USA

Use of 3D Printing Technology to Improve the Voltage Distribution Across Inductor’s Turns
Faisal Alsaif, Prof. Jin Wang
The Ohio State University, USA

Designing of Flying Capacitor (FC) Module based on GaN Chip
Pasan Gunawardena, Xuesong Wu, Prof. Yunwei Li
University of Alberta, Canada

High-Voltage, High-Current Pulse Generator
Xin Zan, Prof. Al-Thaddeus Avestruz
University of Michigan, Ann Arbor, USA

High Performance Integrated Motor Drive using WBG-enabled Current-Source Converters
Renato Amorim Torres, Hang Dai, Prof. Bulent Sarlioglu, Prof. Thomas Jahns
University of Wisconsin-Madison, USA

Composite Hybrid Energy Storage System
Marium Rasheed, Josh Larsen, Prof. Regan Zane
Utah State University, USA

Software Competition

Demonstration of Power Sink with Wide Power-Bandwidth to Emulate Residential Loads
Hitesh Kumar, Prof. Santanu K. Mishra
Indian Institute of Technology Kanpur, India

Machine Learning Methods and Open-Source Database for Magnetic Core Loss Modeling
Haoran Li, Mian Liao, Shukai Wang, Prof. Minjie Chen
Princeton University, USA

Blockchain-Enabled Security Module for Firmware Security-Enhanced Smart Inverter
BoHyun Ahn, Seerin Ahmad, Swathi Pedavalli, Prof. Taesic Kim
Texas A&M University-Kingsville, USA

PowerSynth an MCPMs layout Optimization Tool
Quang Le, Imam Al Razi, Tristan Evans, Prof. Alan Mantooth, Prof. Yarui Peng
University of Arkansas, USA

Active Life Balancing to Condition Li-ion Battery Packs
Marium Rasheed, Prof. Regan Zane
Utah State University, USA
Exhibitor Listing

Allegro MicroSystems
Bodo’s Power Systems
Efficient Power Conversion Corporation
EGSTON Power Electronics
FREEDM Systems Center
GanPower International
GeneSiC
GMW Associates
Halla Mechatronics
How2Power.com
HVR Advanced Power Components Inc.
IEEE Future Networks
IEEE - Industrial Application Society
IEEE - Power Electronics Society
Infineon
Magna-Power
Magnetics
MathWorks
MDPI - Machines
OPAL RT
Payton America Inc
Picotest
Plexim, Inc
Powersim
Richardson RFPD
Rohde & Schwarz USA
Sanrex Corporation
STMicroelectronics
Taiwan Semiconductor Inc.
Vicor
Voltx.ai
Wiley
Wolfspeed
The Fourteenth Annual IEEE Energy Conversion Congress and Exposition (ECCE 2022) will be held in Detroit, Michigan, USA, from October 9 to October 13, 2022. ECCE is a pivotal international event on energy conversion. ECCE 2022 will feature both industry-driven and application-oriented technical sessions as well as an exposition. The conference will bring together practicing engineers, researchers and other professionals for interactive and multidisciplinary discussions on the latest advances in areas related to energy conversion.

Technical papers are solicited on any subject pertaining to the scope of the conference including, but not limited to, the following major topics:

**Energy Conversion Systems & Applications**
- High power/voltage power conversion
- High voltage isolation techniques
- Energy harvesting
- Energy conversion for information technology and communication systems
- Energy efficiency for residential, commercial, and industrial applications
- Big data and artificial intelligence in energy conversion
- Renewable and alternative energy power electronic systems
- Smart grids, microgrids, and utility applications (HVDC, FACTS, and Solid State Transformers)
- Electrical energy storage
- Wireless power transfer

**Component, Converter & Subsystem Technologies**
- Power electronic devices (silicon and wide bandgap) and applications
- Passive components and materials
- Power electronic packaging integration
- Reliability, advanced fault protection systems, diagnostics, prognostics, and health management
- Thermal management and advanced cooling technologies
- Electromagnetic interference and electromagnetic compatibility
- Power conversion topologies, modulation, and control
- Electrical drive systems and topologies and their control
- Rotating/linear electromechanical devices
- Enabling technologies for Industry 4.0: advanced manufacturing, additive manufacturing, digital twins, cloud design, big data analytics

**Digest Submission:** Prospective authors are requested to submit a single column, single spaced digest no longer than five (5) pages summarizing the proposed paper. The digest should include key equations, figures, tables, and references as appropriate, but no author names or affiliations. Digests not conforming to these requirements will be rejected without review. The digests must clearly state the objectives of the work, its significance in advancing the state of the art, and the methods and specific results in sufficient detail. All digests will go through a double-blind peer review process to ensure a confidential and fair review. The papers presented at the conference will be included in the IEEE Xplore Digital Library. Please refer to the conference website for a detailed list of technical topics and the digest submission method.
Call for Tutorials

IMPORTANT DATES

February 11, 2022
Tutorial proposal due

April 8, 2022
Notification of acceptance

July 1, 2022
Full tutorials materials due

The 14th Annual IEEE Energy Conversion Congress and Exposition (ECCE 2022) will be held in Detroit, Michigan, USA, from October 9 to October 13, 2022. ECCE is a pivotal international event on energy conversion. It will bring together practicing engineers, researchers, and other professionals for interactive discussions on the latest advances in areas related to energy conversion.

The ECCE organizing committee invites proposals for tutorials to be presented at ECCE 2022. Each tutorial is 3 hours long, excluding break times. Each accepted tutorial will receive one conference registration together with an honorarium of $1,000. Presenters potentially may be expected to present both in-person and pre-recorded.

Please note that publication of a technical paper will still require a paid full registration. All tutorial proposals should be submitted via the ECCE 2022 web portal under “Call for Tutorials”. Please follow the Tutorial Proposal Form on the website as a submission template. The proposals will be reviewed by a panel of subject matter experts.

One or more of the following elements are strongly encouraged in the tutorial proposals:

- Renewable energy, including under-represented ocean-wave, tidal, geothermal
- Smart grids, micro-grids, nano-grids
- Electrical energy storage, including real physics or controlled virtual storage
- Energy conversion for information technology and communication systems
- Energy harvesting and conversion
- Smart and energy efficient buildings
- Energy efficiency for advanced manufacturing
- Big data and machine learning in energy conversion
- Cybersecurity in energy conversion systems
- Transportation electrification, including aircraft and urban aerial mobility
- Battery charging technologies
- Resiliency in energy systems
- Component, Converter and Subsystem Technologies
- Power electronic devices
- Power conversion topologies, modeling, and control
- Electric machines and drives
- Passive components, magnetics, and materials
- Packaging, integration, and advanced manufacturing
- EMI and EMC
- Thermal management, advanced cooling technologies
- Wireless power transfer
- High voltage power conversion, including insulation technologies
- Design automation or optimization
- Reliability, diagnostics, prognostics, and health management
- Fault-tolerant converters and systems

Potential topic areas include but are not limited to:

- Pedagogy for undergraduate learning or under-represented groups
- Post-COVID technology innovations
- Entrepreneurship, technology transfer, business management
- Use of standards for specific applications
- Industry led or co-hosted lectures;
- Interactive instructor-audience approaches, including hands-on demonstrations and practices;
- Application focused session on tools or methods for the practicing engineer.

Tutorials considered to be less attractive to the audience are:

- a) Topics that are too narrowly focused;
- b) Lectures that are not balanced between theory and application;
- c) Tutorial topics or teams presented previously in immediate past ECCE or other major IAS/PELS conferences;
- d) ECCE 2022 regionally oriented topics at the host city, e.g. transportation electrification;
- e) Collaborative cross-disciplinary topics and tutorial teams are welcome;
- f) Topics that engage the audience in formats that serves to communicate with the attendees.

- Tutorials that narrowly focus on presenter’s own research works that are already publicly available
- Solicitation of a particular product or service.
Format: Maximum 5 pages. All pages are formatted to 8-1/2 by 11 inch or A4 paper with margins of one inch on every side. All texts use single space, Times New Roman, black ink, and a font size of 11 or 12.

Recommended Sections:

1. Tutorial Title

2. Instructor Team
Name(s), affiliation(s), and contact information

3. Abstract
No more than 500 words. Accepted abstract will be published through the conference website, program, and proceedings.

4. Tutorial Outline
Outline shall only define the topics and subtopics. No detailed descriptions please. Time allocation and instructor breakdown by topics is recommended.

5. Lecture Style and Requirements
Briefly describe the tutorial format, which may include traditional lecture, software/hardware demonstration, interactive audience polls/quizzes, worksheets, discussion, etc. Note any equipment or space requirements beyond a laptop and projector. Also list the targeted audience and tutorial difficulty level, including any pre-requisite knowledge.

6. Instructor Biography
No more than 200 words for each person. Each biography shall include the qualifications most relevant to the proposal. Past tutorial/teaching experience and outcome can be highlighted. External website link can be included but may not be reviewed.
The 14th Annual IEEE Energy Conversion Congress and Exposition (ECCE 2022) will be held in Detroit, Michigan, USA, from October 9 to October 13, 2022. Special Sessions are solicited focusing on emerging technologies and industry-oriented topics. Industry and government organizers or speakers are of particular interest. Guest speakers will be invited on the day their session is scheduled. No written papers are required. Materials presented in the Special Sessions will not be included in the conference proceedings. Each session will be assigned either one or two 100-minute slot(s), subject to conference program scheduling.

Different session formats are solicited: 1) Formal presentations; 2) Informal talks with or without slides; 3) Full Q&A panel; 4) Debate; 5) Other creative or hybrid styles.

One or more of the following elements are strongly encouraged in the special session proposals: A) Significant industry or government involvement; B) Industrial application oriented; C) ECCE 2022 regionally oriented topics; D) Collaborative cross-disciplinary topics or teams; E) Creative formats that engage the audience, especially industry.

Factors considered as less attractive to the audience are: a) Non-emerging topics; b) Academic lectures; c) Similar teams with similar topics from the immediate past ECCE; d) Solicitation of a particular product or service; e) Unclear plans including unconfirmed speakers.

Potential topic areas include but are not limited to:

**Energy Conversion Systems and Applications**
- Transportation electrification, including EV, trucks, aircraft, UAV, trains, ships
- Energy storage systems, including real or virtual storage
- Charging stations, vehicle to grid
- Additive manufacturing
- Renewable energy integration
- Smart grids, micro-grids, nano-grids
- Resiliency in energy systems
- Smart and energy efficient buildings
- Energy conversion for information technology
- Big data and machine learning in energy conversion
- Cybersecurity in energy conversion
- Design automation and optimization

**Components, Converters, and Subsystems**
- Power semiconductor devices, magnetics, capacitances
- Power conversion topologies, modeling, and control
- Electric machines and drives
- Packaging, integration, and advanced manufacturing
- EMI and EMC
- Thermal management, advanced cooling technologies
- Wireless power transfer
- High voltage power conversion, including insulation technologies
- Reliability, diagnostics, prognostics, and health management

**Others**
- Advanced testing and validation, including demo
- Standards development
- Education and career development
- Entrepreneurship, technology transfer, business management
- Post-COVID technology innovations

Proposal Submission Guidelines: All special session proposals must be submitted via the ECCE 2022 web portal under “Call for Special Sessions”. Please follow the Proposal Form on the website as a submission template. The proposals will be reviewed by a panel of subject matter experts.
### Special Session Proposal Form

**Format:** Maximum 5 pages. All pages are formatted to 8.5x11” or A4 paper with margins of one inch on every side. All texts use single space, Times New Roman, and a font size of 11 or 12. A Word template will be posted on the official website under Call for Special Sessions.

#### Recommended Sections:

1. **Special Session Title**

2. **Proposed Session Format**

   - [ ] Formal presentations
   - [ ] Informal talks
   - [ ] Full Q&A panel
   - [ ] Debate
   - [ ] Create own style – see Call For Proposal.

   Describe the format at a high level, and note any creative activities such as software/hardware demonstration, virtual tours, interactive audience polls, etc.

3. **Proposed Timing**

   - [ ] 100 minutes
   - [ ] 2x100 minutes

4. **Session Organizers**

   List name(s), title(s), affiliation(s), and email(s).

5. **Session Speakers/Panelists**

   List names, titles, and affiliations. Clearly note each speaker’s availability: choose “confirmed” or “tentative”; failure to do so will be treated as all tentative.

6. **Abstract**

   No more than 500 words. Accepted abstract will be published through the conference website and program book.

7. **Session Outline**

   Only list the proposed topics/titles/activities. No detailed descriptions necessary. Indicate time allocation and speaker breakdown, if possible.

8. **Organizer Biography**

   No more than 200 words for each person. External website link can be included but may not be reviewed.

9. **Speaker/Panelist Biography**

   No more than 200 words for each person. External website link can be included but may not be reviewed.