Morning Sessions:

1. High Power Medium Frequency Transformer Design Optimization 2
2. Model Predictive Control of High Power Converters and Industrial Drives 3
3. Modeling and Energy Management of Modern Shipboard Power Systems 4
4. DC Arc Fault Detection and Protection in DC Electric Power Systems 5
5. Practical Considerations for the Application of High Power Si and SiC Modules 7
6. Isolated Bi-directional DC/DC Converter Topologies and Control 8

Afternoon Sessions:

7. Using Soft-Switching Technology to Design High-Power, High-Current, Isolated, DC/DC Converters that Achieve Low-Cost, High Reliability, and Electromagnetic Compliance 9
8. SiC Power Device Design and Fabrication, and Insertion in Novel MV Power Conversion Systems 11
9. Electric Energy Storage Systems and Energy Management Solutions for Future Electric Transportation and Mobility 12
10. Electrical Machine Analysis using Free Software 13
11. EMI Issues and Solutions in PWM Converters 16
12. Wireless Power Transfer for Electric Vehicle and Mobile Applications 17

1. High Power Medium Frequency Transformer Design Optimization

Instructors: Prof. Drazen Dujic and Mr. Marko Mogorovic,
Power Electronics Laboratory, Swiss Federal Institute of Technology, Switzerland.

Abstract: With increased interest in Power Electronic Transformers or Solid State Transformers, several technical problems arise related to actual realization of these technologies. Irrespectively of adopted power electronic topologies, these structures are characterized as being modular and having inherently built-in galvanic isolation at medium or high frequency. The implementation of the galvanic isolation can be achieved either with a single transformer or, as often the case, multiple smaller power rated transformers depending on the given design objectives and constraints. However, designing a high-power high-voltage medium frequency transformer is associated with multiple technical challenges related to electrical, magnetic, dielectric and thermal performance limits encountered in the system.

Various technological choices must be carefully considered and selected before being included into a generic multi-objective optimization. Moreover, the quality of the result of the optimization is only as good as the utilized models. Therefore, all relevant phenomena, within physical subsystems of this complex multi-physical system, must be modelled both accurately and precisely in reference to their impact on the given application. Optimization goals will depend on various parameters, such as application requirements regarding weight, volume, form factor, efficiency, thermal constraints, costs, etc.

Tutorial will provide an overview and address challenges coming from the application area, characteristics of involved materials and available design choices, associated modelling of different elements impacting medium frequency transformer design, as well as optimization process as whole. Multiple illustrative design examples will be critically analyzed in terms of their key performance indicators, and supported with practical examples realized by the tutorial instructors themselves.

Drazen Dujic is an Assistant Professor and Head of the Power Electronics Laboratory at EPFL. He received the Dipl.Ing. and MSc degrees from the University of Novi Sad, Novi Sad, Serbia in 2002 and 2005, respectively, and the PhD degree from Liverpool John Moores University, Liverpool, UK in 2008. From 2003 to 2006, he was a Research Assistant with the Faculty of Technical Sciences at University of Novi Sad. From 2006 to 2009, he was a Research Associate with Liverpool John Moores University. After that he moved to industry and joined ABB Switzerland Ltd, where from 2009 to 2013, he was Scientist and then Principal Scientist with ABB Corporate Research Center in Baden-Dättwil, and from 2013 to 2014 he was R&D Platform Manager with ABB Medium Voltage Drives in Turgi. In 2014, he received The Isao Takahashi Power Electronics Award for Outstanding Achievement in Power Electronics, presented at International Power Electronics Conference, IPEC-Hiroshima 2014, Japan.

Marko Mogorovic received the Dipl.Ing. degree from the University of Belgrade, Belgrade, Serbia, in 2013 and MSc degree from the École polytechnique fédérale de Lausanne (EPFL), Lausanne, Switzerland, in 2015. Currently, he is pursuing the Ph.D. degree at Power Electronics Laboratory at EPFL, Lausanne, Switzerland. His current research focus is on the design optimization of the high power medium frequency transformers for medium voltage applications and emerging solid state transformers.

2. Model Predictive Control of High Power Converters and Industrial Drives

Instructors: Tobias Geyer, ABB Corporate Research Switzerland

Abstract: This tutorial focuses on model predictive control (MPC) schemes for industrial power electronics. The emphasis is put on three-phase ac-dc and dc-ac power conversion systems for high-power applications of one MVA and above. These systems are predominantly based on multilevel voltage source converters that operate at switching frequencies well below one kHz. The tutorial mostly considers medium-voltage (MV) variable speed drive systems and, to a lesser extent, MV grid-connected converters, including modular multilevel converters. The proposed control techniques can also be applied to low-voltage power converters when operated at low pulse number, i.e. at small ratios between the switching frequency and the fundamental frequency. Examples for this include automotive and railway traction converters.

For high-power converters, the pulse number typically ranges between five and 15. As a result, the concept of averaging, which is commonly applied to power electronic systems to conceal the switching aspect from the control problem, leads to a performance deterioration. In general, to achieve the highest possible performance for a high-power converter, averaging is to be avoided and the traditionally used current control loop and modulator should be replaced by one single control entity.

This tutorial proposes and reviews control methods that fully exploit the performance potential of high-power converters, by ensuring fast control at very low switching frequencies and low harmonic distortions. To achieve this, the control and modulation problem is addressed in one computational stage. Long prediction horizons are required for the MPC controllers to achieve excellent steady-state performance. The resulting optimization problem is computationally challenging, but can be solved in real time by branch and bound methods. Alternatively, the optimal switching sequence to be applied during steady-state operation—the so-called optimized pulse pattern (OPP)—can be pre-computed offline and refined online to achieve fast closed-loop control. To this end, the research vision is to combine the benefits of deadbeat control methods (such as direct torque control) with the optimal steady-state performance of OPPs, by resolving the antagonism between the two. Three such MPC methods are presented in detail.

This tutorial follows a book by the instructor, which was published by Wiley in 2016. Some of the proposed MPC methods have been introduced in commercial products. Experimental results from pilot installations will be shown and discussed. The tutorial aims at providing a balanced mix of theory and application-related material. Special care is taken to ensure that the presented material is intuitively accessible to the power electronics practitioner. This is achieved by augmenting the mathematical formulations by illustrations and simple examples.

Tobias Geyer received the Dipl.-Ing. and Ph.D. degrees in electrical engineering from ETH Zurich, Zurich, Switzerland, in 2000 and 2005, respectively. From 2006 to 2008, he was with the High Power Electronics Group of GE's Global Research Centre, Munich, Germany, where he focused on control and modulation schemes for large electrical drives. Subsequently, he spent three years at the Department of Electrical and Computer Engineering, The University of Auckland, Auckland, New Zealand, where he developed model predictive control schemes for medium-voltage drives. In 2012, he joined ABB's Corporate Research Centre, Baden-Dättwil, Switzerland, where he is currently a Senior Principal Scientist for power conversion control. He is also a lecturer at ETH Zurich.

3. Modeling and Energy Management of Modern Shipboard Power Systems

Instructors: Osama A. Mohammed, Christopher R. Lashway
Florida International University

Abstract:
This tutorial is geared toward an intermediate-level audience, but will provide an extensive review of shipboard power systems from fundamentals to advanced energy management and design. Beginning with a general overview of the most popular architectures, configurations, and ratings, an extension will be made into a review of applicable standards. Three popular configurations are discussed in the progression to an all-electric ship. The all-electric ship brings with itself a new focus beyond the legacy main and auxiliary turbine generators to the integration of efficient energy storage devices. Current energy storage technologies are no longer limited to battery chemistry and size, but also utility-grade supercapacitors and flywheel energy storage, a combination commonly referred to as hybrid energy storage systems. While introducing these elements improves power delivery capabilities on a ship, hybrid energy storage systems introduce new dynamics making their design and utilization challenging. A number of facets related to their integration and control is discussed from selection to optimization. Combinations of batteries with supercapacitors and flywheel energy storage are tested, optimized, and evaluated for their use in shipboard power applications. An in-depth review of hybrid energy storage systems and how they can be combined to mitigate the impacts of hotel, pulsed, and multi-pulsed loads is also discussed. A discussion over a specialized power system testbed is provided and used as a platform to apply new hybrid microgrid control schemes. A shipboard test bed platform at the Energy Systems Research Laboratory at Florida International University is introduced and used as a comprehensive experimental testing platform to support the evaluation of various hybrid energy storage systems and their associated control topologies.

Osama A. Mohammed is a Professor of Electrical Engineering and is the Director of the Energy Systems Research Laboratory at Florida International University, Miami, Florida and is an elected fellow of IEEE. He received his MS and PhD degrees in Electrical Engineering from Virginia Tech in 1981 and 1983, respectively. He has performed research on various topics in power and energy systems. Additionally, he has interest in computational techniques and design optimization in electric drive systems and other low frequency environments. He performed multiple research projects for several Federal agencies since 1990's dealing with: power system analysis, physics based modeling, EMI and EM signatures, sensorless control, high frequency switching. He also performed funded research in ship power systems as well as energy cyber physical systems and transportation electrification and currently has active research programs in a number of these areas funded by DoD, the US Department of Energy and several industries. Professor Mohammed is a world renowned leader in electrical energy systems, computations and intelligent systems having published more than 450 articles in refereed journals and other IEEE refereed conference proceedings.

Christopher R. Lashway received his B.S. in electrical engineering technology at the University of Central Florida, Orlando in 2008 and M.Eng. degree in electrical engineering at Pennsylvania State University – Harrisburg in 2010. He moved on to work as an engineer for the Naval Surface Warfare Center in Dahlgren, Virginia on a wide range of Marine Corps and Naval projects focusing on mobile power and energy solutions. From 2010 to 2012, he supported the Squad Electric Power program, an effort focused on consolidating proprietary non-rechargeable batteries found in tactical radios and night vision equipment through developing a central power manager with a lithium ion battery pack while integrating solar and mechanical charging techniques. He is a currently a PhD candidate at the Energy Systems Research Laboratory at Florida International University in Miami, FL where his research is focused on hybrid energy storage modeling and control. Christopher has published in 4 top-tier journals as well as 12 conference proceedings supporting his work within this field and currently has a patent pending in the design of a modular energy storage management controller.

4. DC Arc Fault Detection and Protection in DC Electric Power Systems

Instructors:
Xiu Yao, University at Buffalo
Jin Wang, The Ohio State University
Luis Herrera, Rochester Institute of Technology

Abstract:
This professional education seminar will systematically cover various aspects of dc arc fault detection in emerging dc power applications. A comprehensive review of dc arc fault modeling approaches and their applications will be presented in detail. The principles and developments of various dc arc fault detection techniques will be then introduced. The state-of-the-art detection techniques in both literatures and commercial products will be presented. Moreover, the detection of dc arc faults in the context of a modern dc power systems with advanced power electronics interfaces and controllers will be discussed, including the impact of dc arc faults on the control of dc microgrids, as well as hardware-in-the-loop based validation methods.

The goal of this seminar is to introduce the state-of-the-art technologies and to discuss future research and development needs of dc arc fault protection in modern dc networks. It is dedicated to help the audience better understand the issues of dc arc faults and system level protection of dc systems. It will be of direct interest to researchers and engineers who work with dc arc fault interrupters and PV inverters. It should also be of interest to engineers who work with dc mcirogrids, dc distribution systems, and development of dc system protection standards.

The first session is an introduction of dc arc fault and related issues, covering dc electric networks and general aspects on system level protection, dc arc faults: fault mechanisms, fault types, and hazards, and DC arc fault related standards and industry practice. The second session is about the DC arc modeling, covering the external characteristics modeling such as arc V-I equations, development history, derivation procedures, experimental conditions, and limitations, high frequency modeling of arc current signals using probabilistic methods and various types of arc models for system level simulations and analysis. The third session discusses DC arc fault detection techniques: different aspects of dc arc fault detection techniques including signal sensing, fault signature selection and computation, and fault detection algorithms, a comprehensive review of signal sensing and fault signature selections in time, frequency, and time-frequency domains, a review of fault detection algorithms, and commercial products: requirements, principles, and performance evaluation. The fourth session is on DC arc fault in microgrids: basic concepts of dc microgrids, conventional and advanced control methods of dc microgrids, case study on the interaction of dc arc faults with microgrid control and operation, and dc arc fault protection in dc microgrids.

Xiu Yao is an Assistant Professor in the Dept. of Electrical Engineering at University at Buffalo. She received a Ph.D. degree in Electrical Engineering from The Ohio State University, Columbus, in 2015. She received her B.S. and M.S. degrees in Electrical Engineering from Xi'an Jiaotong University, China, in 2007 and 2010, respectively. Dr. Yao was awarded the U.S. Air Force Summer Faculty Fellowship to work at Wright-Patterson Air Force Base, Dayton, OH, 2016. She has authored 30+ peer reviewed papers. Her research interests include dc system control, protection, and energy management, high power electronics applications, and high voltage dc transmission.

Jin Wang received his B.S. degree from Xi'an Jiaotong University, in 1998, M.S. degree from Wuhan University, in 2001, and Ph.D. degree from Michigan State University, in 2005. From Sept. 2005 to Aug. 2007, he worked at the Ford Motor Company. He joined The Ohio State University as an assistant professor in September 2007 and was promoted to associate professor in 2013. His research interests include wide bandgap power devices and their applications, high voltage and high-power converter/inverters, integration of renewable energy resources, and electrification of transportation. Dr. Wang received the IEEE Power Electronics Society Richard M. Bass Young Engineer Award and National Science Foundation's CAREER Award, both in 2011. He has over 100 peer-reviewed journal and conference publications and five patents.

He was an Associate Editor for the IEEE Transactions on Industry Applications from 2008 to 2014. He initiated and chaired the 1st IEEE Workshop on Wide Bandgap Power Devices and Applications in 2013 and served as the guest Editor for the Special Issue on Wide Bandgap Power Electronics in IEEE Journal of Emerging and Selected Topics in Power Electronics in 2016. Currently, Dr. Wang also serves as an Associate Editor for the IEEE Transactions on Power Electronics.

Luis Herrera is an Assistant Professor in the Electrical and Microelectronic Engineering Department at the Rochester Institute of Technology (RIT). Prior to joining RIT, he worked for the University of Dayton Research Institute as a Research Engineer on a project for the Air Force Research Laboratory in Wright Patterson Air Force Base, OH. He received his Ph.D. in Electrical Engineering with a focus on Power Electronics and Control from The Ohio State University in 2015 and a B.S. in Engineering from the University of Tennessee at Martin with a minor in physics. His research interests include the integration of renewable sources and energy storage to the power grid and ac and/or dc microgrids, modeling and control of power electronic systems, and Hardware in the Loop verification strategies.

5. Practical Considerations for the Application of High Power Si and SiC Modules

Instructors: John F. Donlon, and Eric R. Motto, Powerex, Inc.

Abstract: High Power Semiconductor modules are the workhorse power switch for industrial applications. This seminar will discuss the issues a designer must deal with in using these devices including interpretation of device ratings, gate drive requirements, and providing device and system protection. The presentation will include an update of the latest developments in Si and SiC power modules. The intent of this tutorial is to aid the designer in choosing and applying a power module to a new product. Questions and concerns a designer might have will be addressed by the various techniques and circuit examples that will be presented. Chip technology and packaging options will be discussed with special attention to the tradeoffs between silicon and silicon carbide. The practical application of SiC power devices today and in the future will be discussed. The attendee should leave the course with a better understanding of the power module, specifically as a device and how it functions in an application. The goal will be to impart an understanding of desirable features, characteristics, and limitations. This will include the application in power circuits, protection from internal and external disturbances, and an understanding of thermal design, handling, and reliability considerations. The tutorial is intended for design engineers having to deal with confusing and conflicting information on device data sheets and should be of interest to anyone who uses, applies, procures, or specifies power electronic products based on high power IGBTs or SiC MOSFETs as the power switch.

The high level outline of this tutorial is arranged as the following:
1) Basic Characteristics, Failure Modes, and Reliability: overview, static & dynamic characteristics, thermal resistance, switching SOA, SCSOA; 2) Chip and packaging technology update: trend, vertical structures, high reliability packaging, SiC and Si; 3)Application Considerations: voltage & current ratings, thermal & power cycling, parallel connections; 4) Design Examples: loss calculations, loss simulator, sanity check; 5) Gate Drive Circuit Design: Vge(on), Vge(off) Rg, gate current and power, Vce sensing, desaturation detection, layout, hybrid gate drivers; 6) Power Circuit Design: stray inductance, laminated bus bar, snubbers.

John F. Donlon received the B.S. degree with high honors in Electrical Engineering from the Lowell Technological Institute and the M.S. degree in Electrical Engineering from Syracuse University. He is Senior Engineer at Powerex, Inc. in Youngwood, PA and has been involved in the rating, evaluation, and application of power semiconductors for forty years. He has been active in the publication of over ninety-five technical papers, articles, and application notes describing the characteristics and proper application of power semiconductors.

Eric R. Motto is Chief Engineer with Powerex. He holds a Bachelor of Science in Electrical Engineering from Pennsylvania State University and a Bachelor of Arts in Mathematics from Saint Vincent College. From 1987 to 1990 Eric worked as a design engineer at Lutron Electronics in Coopersburg Pennsylvania developing circuits for the control and stabilization of electronic dimming ballasts. Since 1990 Eric has been with Powerex, Inc. in Youngwood Pennsylvania providing technical support for users of Mitsubishi power semiconductor devices in North America. Eric has written and presented more than forty technical papers at industry conferences and published numerous application notes and magazine articles related to the design and application of IGBT and Intelligent Power Modules.

6. Isolated Bi-directional DC/DC Converter Topologies and Control

Instructors: Mark Dehong Xu, Zhejiang University.

Abstract: Isolated Bi-directional DC/DC conversion is key technology for Renewable Power Systems, Battery Energy Storage Systems, bidirectional on-board EV charger, Solid State Transformer etc. In this tutorial firstly basics of bidirectional DC/DC converters is presented. A classification of bi-directional DC/DC converters, and their application are explained. Dual Active Bridge (DAB) converter and its power regulation with phase-shift control is introduced. Soft switching condition with load condition is discussed. Alternative PWM modulations for DAB are investigated with regards to the soft switching condition or conversion efficiency enhancement. Then bidirectional converters with the resonant circuit is introduced. It bidirectional power control method is discussed. It is compared with Dual Active Bridge (DAB) converter. With regards to the Dual Active Bridge (DAB) converter, various modulation methods are discussed and compared.

To further accommodating either input or output terminal voltage variation, PWM plus Phase-Shift control (PPS) is introduced. It combines the advantage of both pulse width modulation and phase-shifting control. Pulse width modulation is more adapted to variation of the terminal voltages with lower current stress and lower conducting loss in power devices while phase-shifting control is more suitable to Zero Voltage Switching condition for power devices in the converter. The novel scheme is explained with stages analysis and ZVS condition derivation. Finally an experiment prototype is described. Systematic synthesis methods for bidirectional converters which can realize PPS control is presented. A family of bidirectional converters with PPS is derived. Bi-directional DC/DC converters with PPS control is MIMO control system. The dynamic model is needed for analytical controller design.

Resonant bidirectional DC/DC converters are introduced. Since the resonant converter is implemented in these bidirectional DC/DC converter, the dynamic loss of the power device is significantly reduced in comparison with PWM controlled bidirectional converters. Therefore high switching frequency may be used and the isolation transformer can be significantly reduced, which is suitable to the application of SST and battery energy systems. Finally examples of applications of bidirectional DC/DC converter are introduced such as V2G on-board EV charger, and DC solid state transformer.

Mark Dehong Xu is a professor and the director of the Power Electronics Institute of Zhejiang University in China. He was a visiting scholar in University of Tokyo, CPES of Virginia Tech, and ETH. The focus of his current research is on power conversion topology, modeling, control for renewable energies and energy efficiency. Besides he also work on soft switching power conversion and applications. He is an at-large Adcom member of IEEE Power Electronics Society from 2006-2008 and 2017-2019. He serves as an associate editor of IEEE transaction on power electronics etc. He was General Chair of IEEE ISIE2012 at Hangzhou, IEEE PEDG2013 at Arkansas, IEEE PEAC2014 at Shanghai, and IEEE IFEC2015. He received IEEE Power Electronics Society's R. D Middlebrook Achievement Award in 2016. Dr. Xu is a Fellow of the IEEE. He serve as an IEEE PELS Distinguished Lecturer in 2015-2016 and 2017-2018.

7. Using Soft-Switching Technology to Design High-Power, High-Current, Isolated, DC/DC Converters that Achieve Low-Cost, High Reliability, and Electromagnetic Compliance.

Instructors:
Alexander (Sasha) Isurin, Vanner Inc.
Mark Scott, Miami University

Abstract: This tutorial presents design strategies for isolated, step-up and step-down, DC-DC converters that utilize soft-switching technology. It focuses on topologies where the low-voltage terminals of the converter conduct several hundred amps at power levels of 2 kW and beyond. The audience learns how to leverage soft-switching technology to create hardware that is low cost, highly reliable, and achieves electromagnetic compatibility (EMC). The discussion includes how to choose a soft-switching topology for a given application, specify its components, and select the topology's commutation frequency. Furthermore, principles for designing high-current, high-frequency transformers are included in the presentation. Experimental results are provided to validate the proposed design strategies. While these results focus on applications in electrified transportation, the concepts that are presented are general, and they can be applied to other fields such as power supplies for data centers and in renewable energy applications.

The four technical components of this seminar are: (1) metrics for evaluating power electronics, (2) a review of soft-switching principles, (3) a survey of isolated DC/DC converters that use soft switching, and (4) guidelines for designing high-current, high-frequency transformers. The first topic demonstrates how *cost*, *reliability*, and *EMC* drive design decisions in electrified transportation applications. The influence of magnetics and active power devices on these metrics is emphasized in this section. During the second topic, soft-switching technology is covered. First, the pulse width modulation (PWM) strategies that are used to achieve output regulation are presented. Next, an overview of zero voltage switching (ZVS) and zero current switching (ZCS) technologies are discussed. The third topic compares and contrasts the seven types of resonant converters topologies. Basic operating principles for each topology are discussed along with the strengths and weaknesses of each approach. For each topology, recommended applications will be provided along with methods for selecting components and choosing the switching frequency. The fourth topic focuses on the high frequency transformer design and provides guidelines to successfully implement them into high current applications. Finally, the tutorial concludes with a broad summary. To facilitate an open dialogue, questions are encourage throughout the presentation.

Alexander Isurin received the M.S. degree in electrical engineering from the University of Communication, St. Petersburg, Russia. After that, he joined the power electronics industry and has attained a broad engineering experience in three countries, including Russia, Israel, and the United States. Mr. Isurin's design experience includes: electronic welding devices, charging devices for electronic vehicles, and custom industrial power supplies of a high power levels. Most recently he as designed several bidirectional, isolated, resonant converters for low voltage high current applications. He is an author of many patents on power conversion technology, control of power electronics, and gate drives. His topologies have been implemented, or are being implemented, in the automotive industry. He is a Senior Engineer: Power Conversion Specialist with Vanner, Inc., located in Hilliard, OH, USA. His current research interests include high-frequency power conversion using soft switch technology, with an emphasis on cost effectiveness and high efficiency.

Mark J. Scott received his B.S. (2005), M.S. (2013) and Ph.D. (2015) degrees from The Ohio State University. His dissertation topic utilized wide bandgap (WBG) power devices in converters and multilevel inverters based on switched-capacitor cells. Between his undergraduate and graduate degrees, he worked in industrial automation and as a test engineer validating power electronics designed for vehicles. Dr. Scott is an assistant professor at Miami University in Oxford, OH. His research focuses on improving the efficiency and increasing the reliability of power electronic hardware. He is studying the benefits of using silicon carbide (SiC) and gallium nitride (GaN) power devices in electrified transportation and solar power systems. Additionally he is investigating the advantages of using resonant switching technology in these applications.

8. SiC Power Device Design and Fabrication, and Insertion in Novel MV Power Conversion Systems

Instructors: Subhashish Bhattacharya, Victor Veliadis, North Carolina State University.

Abstract: The tutorial will outline the advantages of SiC over other power electronic materials, and will introduce SiC devices currently developed for power electronic applications. ESD, high-voltage testing, and packaging aspects will be covered. The design and properties of SiC JFETs, MOSFETs, BJTs, IGBTs, Thyristors, and Junction Barrier Schottky and PiN diodes will be discussed, with an emphasis on their performance advantages over those of their Si counterparts. Common SiC Edge Termination techniques, which allow SiC devices to exploit their full high-voltage potential, will be rigorously treated and their impact on device performance will be highlighted. Aspects of device fabrication will be taught with an emphasis on the processes that do not carry over from the mature Si manufacturing world and are thus tailored to SiC. In particular, the tutorial will stress in-depth the design and fabrication of SiC MOSFETs, which are being inserted in the majority of SiC based power electronic circuits. Device reliability will be reported through exemplary hard switching and unclamped inductive load results. Exemplary SiC-based power electronics systems will be presented, and their numerous advantages over conventional Si systems will be articulated.

The opportunities for HV SiC devices for MV Power Converters and utility applications and the challenges to apply these HV SiC devices successfully will be presented in-depth with SiC device voltage ranges from 1200 V to 1700 V MOSFETs, and HV 10 kV - 15 kV MOSFETs, JBS diodes, and 15 kV SiC IGBTs. The potential and challenges of the HV 10-15 kV devices to enable MV power conversion systems, including MV motor drives, FACTS and MVDC grids will be explored. Challenges in adopting these HV SiC devices for MV power conversion in terms of magnetics, capacitors, and insulation materials will be discussed.

Subhashish Bhattacharya received his B.E. (Hons), M.E. and PhD degrees in Electrical Engineering from Indian Institute of Technology-Roorkee (formerly University of Roorkee), India in 1986, Indian Institute of Science (IISc), Bangalore, India in 1988, and University of Wisconsin-Madison in 2003, respectively. He worked in the FACTS and Power Quality group at Westinghouse R&D Center in Pittsburgh which later became part of Siemens Power Transmission & Distribution, from 1998 to 2005. He joined the Department of Electrical and Computer Engineering at North Carolina State University (NCSU) in August 2005, where he is the ABB Term Professor, and also a founding faculty member and co-PI of NSF ERC FREEDM systems center (www.freedm.ncsu.edu), Advanced Transportation Energy Center [ATEC] (www.atec.ncsu.edu) and the newly established DOE initiative on WBG based Manufacturing Innovation Institute – PowerAmerica - at NCSU. He has authored over 250 peer-reviewed technical articles, 2 book chapters, and has 4 issued patents to his credit. His research interests are Solid-State Transformers, MV power converters, FACTS, Utility applications of power electronics and power quality issues; high-frequency magnetics, active filters, and application of new power semiconductor devices such as SiC for converter topologies.

Victor Veliadis received the Masters and Ph.D. degrees from Johns Hopkins University in 1992 and 1995, respectively, all in Electrical and Computer Engineering. From 1996 to 2000, he was with start-up Nanocrystals Imaging Corporation where he developed quantum-dot phosphors for imaging applications. From 2000 to 2003, he was with Lucent Technologies where he designed InP-based tunable photonic integrated circuits for telecommunication applications. In 2003, Victor was Adjunct Physics Professor at Ursinus College and St. Joseph's University. After a brief military service, Victor joined Northrop Grumman Electronic Systems in 2004 where he designed, fabricated, and tested SiC JFETs, MOSFETs, Thyristors, and JBS, Schottky, and PiN diodes in the 1-12 kV range. In 2016 Victor was appointed CTO and interim Deputy Director of Power America, which is a U.S Department of Energy wide bandgap device Manufacturing Institute managed by North Carolina State University (NCSU). At the time, Victor also became Professor in Electrical and Computer Engineering at NCSU. Victor has authored or co-authored 105 peer-reviewed technical articles, 3 book chapters, and has 24 issued patents to his credit.

9. Electric Energy Storage Systems and Energy Management Solutions for Future Electric Transportation and Mobility

Instructors: Sheldon S. Williamson, University of Ontario-Institute of Technology (UOIT), Canada

Abstract: It must be noted that this tutorial will be particularly useful for engineers and managers with entry-level and medium-level knowledge of power electronics. The tutorial would also be appropriate for engineers with entry-level knowledge of power electronics applications for electric energy storage systems and electric transportation.

Enhancing the life of Lithium-ion (Li-ion) battery packs has been the topic of much interest in the auto industry. In this framework, the role of on-board cell voltage balancing of Li-ion batteries will be highlighted in this tutorial. This is a very important topic in the context of battery energy storage cost and life/state-of-charge, SOC/state-of-health, SOH monitoring. Li-ion batteries, although popularly proposed for electric transport, have been highly uneconomic for energy storage, overshooting cost requirements by a large margin. Li-ion batteries provide a reasonable solution; however, the main issues include: Cycle life (range anxiety), calendar life, energy density, power density, and safety. These issues can be addressed effectively by using a simple practical approach: a power electronics based dynamic cell voltage equalizer. The design and implementation of both inductor-based as well as switched capacitor DC/DC converters for Li-ion battery cell-equalization will be discussed. Fundamental topologies of power electronic converters, specifically utilized for bidirectional current flow in cell balancing applications, will be discussed. The design, implementation, and testing/validation of an active cell equalization circuit for a traction Li-ion battery pack will be presented.

This tutorial will also look at power and energy storage issues related to future e-autonomous mobility as well as urban mass transit applications, such as heavy-duty buses, trucks, trains, and trams – systems which depict frequent start/stop duty cycles. Some of the burning issues and opportunities of using power-packed ultracapacitor (UC) banks on-board heavy-duty transit propulsion systems, with frequent start-stop driving patterns, will be presented. Bidirectional DC/DC converter topologies, designed specifically to recover large amounts of regenerative currents (around 200A), will be presented. Another critical aspect of this tutorial will focus on the design of an innovative DC/DC power electronic converter for UC-bank switching – in order to meet energy demands, rather than just power bursts. A simple and effective technique will be presented to achieve fair amounts of energy storage from UCs, by maintaining the UC bank voltage within a certain threshold. The presented techniques in this tutorial will help overcome the unpopular lower energy densities of UCs and their linear voltage-charge relationship. This technique will increase the energy utilization of UCs, thereby downsizing the number of UCs required for an e-traction application. Modeling, analysis, simulations, and experimental verification will be presented.

Sheldon S. Williamson received his Bachelors of Engineering (B.E.) degree in Electrical Engineering with high distinction from University of Mumbai, Mumbai, India, in 1999. He received the Masters of Science (M.S.) degree in 2002, and the Doctor of Philosophy (Ph.D.) degree (with Honors) in 2006, both in Electrical Engineering, from the Illinois Institute of Technology, Chicago, IL, specializing in automotive power electronics and motor drives, at the Grainger Power Electronics and Motor Drives Laboratory. From June 2006 to May 2011, Dr. Williamson held a Tenure-track Assistant Professor position in the Department of Electrical and Computer Engineering, at Concordia University, in Montreal, Canada. Also, from June 2011 to June 2014, Dr. Williamson held a tenured Associate Professor position at Concordia University. Currently, Dr. Williamson is an Associate Professor at the Smart Transportation Electrification and Energy Research (STEER) group, within the Department of Electrical, Computer, and Software Engineering, at the University of Ontario-Institute of Technology (UOIT), in Oshawa, Ontario, Canada. He is also the recipient of the prestigious NSERC Canada Research Chair in Electric Energy Storage Systems for Transportation Electrification, at UOIT, since Sept. 2015. His main research interests include advanced power electronics and motor drives for transportation electrification, electric energy storage systems, and electric propulsion.

10. Electrical Machine Analysis using Free Software

Instructors:
Nicola Bianchi, University of Padova
David Meeker, QinetiQ North America
Johan Gyselinck , Université Libre de Bruxelles
Ruth V. Sabariego, KU Leuven
Luigi Alberti, Free University of Bozen
Gianmario Pellegrino, Politecnico di Torino
Francesco Cupertino, Politecnico di Bari

Abstract: The design of competitive and efficient electrical machines is to date an open and fascinating engineering challenge. Electrical machines involve a variety of transversal aspects including multiple physical fields, cost and availability of materials and ease of manufacturing. Design goals are also numerous: efficiency, cost, minimum weight, safe operation at high temperature. The rocketing growth of computational power has revolutionized the field of electrical machine design and opened new opportunities for improvement. This tutorial brings together a team of researchers actively involved in developing open-source software dedicated to design and in particular the design of electrical machines.

Software 1: Finite Element Method Magnetics (FEMM) is an open-source magnetic finite element program that is widely used for analyzing electric machines. This presentation will provide an overview of the program, where to obtain it and get support; and how to set up and solve basic problems. Options for scripting interfaces to other commonly used numerical analysis tools (*e.g.*Matlab, Mathematica) will also be described. The FEMM software tool is applied to the analysis of a PM machine.

Software 2: GetDP is an open-source finite-element solver for electromagnetic, thermal, mechanical and acoustic problems, as well as their coupling. These problems are 1D, 2D or 3D, and the resolution is done either statically, in the time domain (time stepping) or in the frequency domain (with one or more frequencies). GetDP does not have its own graphical interface; instead the complete problem, including the partial-differential equation, is transcribed into text data files.

Software 3: Gmsh is an open-source 3D mesh generator with built-in pre- and post-processing facilities. Its design goal is to provide a fast, light and user-friendly meshing tool with parametric input and advanced visualization capabilities. Gmsh is built around four modules: geometry, mesh, solver and post-processing. The specification of any input to these modules is done either interactively using the graphical user interface or in text data files using Gmsh own scripting language.

Software 4: ONELAB (Open Numerical Engineering LABoratory) is an open-source, lightweight interface to finite-element software. The default ONELAB bundle is built on Gmsh GUI, with direct access to all its mesh features, and integrates the finite-element software GetDP. However many other codes (free or not) can be easily interfaced as well.

Software 5: *Koil* is an open source software to design the windings of rotating electrical machinery. It is written in C++ using cross-platform technology. *Koil* manages both the synthesis (design) and the analysis of the windings. Standard symmetrical windings are automatically generated starting from the number of phases, poles and slots. Custom windings (including non-symmetrical ones) can be introduced using a scripting environment.

Software 6: SyR-e is an open-source design tool running in Octave / Matlab and based on FEMM. Initially made for the automatic design of synchronous reluctance machines, SyR-e now covers PM synchronous machines more in general. Besides magnetic design, thermal and structural aspects are included into SyR-e in the form of simplified models with seamless execution time.

Nicola Bianchi received the Laurea and Ph.D. degrees in electrical engineering at University of Padova, Padova, Italy, in 1991 and 1995, respectively. Since 2005 he is an Associate Professor in Electrical Machines, Converters and Drives. His activity is in the Electric Drive Laboratory, Department of Industrial

Engineering, University of Padova. His research and teaching activities include the design of electrical machines, particularly for drive applications. He is responsible for various projects for local and foreign industries. He is author and co-author of several scientific papers on electrical machines and drives, and international books on the same subject. He is a 2014 IEEE Fellow.

David C. Meeker received the B.S. degree in mechanical engineering from Duke University, Durham, NC, in 1990 and the M.S. and Ph.D. degrees in mechanical and aerospace engineering from the University of Virginia, Charlottesville, in 1993 and 1996, respectively. Since 1998, he has worked on the design, analysis, and control of novel electric machines at QinetiQ North America in Waltham, MA, where his present role is Principal Scientist. He is the author of the magnetics finite element analysis program FEMM, which has been used by various authors in many publications. He is an IEEE member.

Johan J. C. Gyselinck obtained his M.Sc. and PhD degree in electromechanical engineering at the Ghent University (Belgium) in 1991 and 2000 respectively. From 2000 till 2004 he was postdoctoral researcher and lecturer at the University of Liège (Belgium). Since 2004 he is professor at the Université Libre de Bruxelles (ULB, Belgium). His main teaching and research activities are situated in the domain of low-frequency numerical magnetics, and electrical machines and drives. The magnetics branch comprises advanced numerical methods for finite-element modeling (material modeling, homogenization in lamination stacks and windings considering eddy-current effects, harmonic balance, etc), using the open-source programs Gmsh and GetDP, and their practical application to electrical machines and other devices. The research on electrical drives (of various types: PMSMs, SRMs, IMs) is focused on control, fault detection, and vibrations and acoustics, and is carried out both via simulation (e.g. with Simulink) and experimentally. 146 words

Ruth V. Sabariego is associate professor with the Department of Electrical Engineering at the KU Leuven, Belgium, since October 2013. She graduated in Telecommunication Engineering in 1998 at the University of Vigo, Spain. From August 1998 till September 2000, she was a research assistant at the Department of Communication Technology, University of Vigo, Spain. In October 2000, she joined the Department of Electrical Engineering and Computer Science, University of Liège, Belgium, where she received the PhD degree in Applied Sciences in 2004 and stayed as a post-doctoral researcher till September 2013. She was a visiting professor at Helsinki University of Technology in September 2009, at the Ecole Centrale de Lyon, France, in June 2009 and June 2012, and at the Grenoble INT, France, in April 2015. Her primary area of expertise involves applied mathematics and computational electromagnetics with a current focus on multi-physics and multiscale modelling.

Luigi Alberti received the Laurea degree and the PhD in Electrical Engineering from the University of Padova in 2005 and 2009, respectively. From 2009 to 2012 he was Research Associate at the University of Padova. In 2012 he moved to the Faculty of Science and Technology at the Free University of Bozen-Bolzano, Italy, to start research and educational activities in the field of electrical engineering and electrical machines. He is currently Associate Professor at the Faculty of Science and Technology of the Free University of Bozen-Bolzano, working on design, analysis and control of electric machines and drives, with particular interest in renewable energies and more electric vehicles.

Gianmario Pellegrino, is an Associate Professor with the Politecnico di Torino. His research interests include the design of electrical machines and the control of electrical drives. He is involved in research projects with industry and has 30 journal papers and one patent. Dr. Pellegrino is an Associate Editor for the IEEE Transactions on Industry Applications and an IEEE Senior Member. He is the co-recipient of five Prize Paper Awards. He was a visiting scholar at Aalborg University, Denmark, in 2002, Nottingham University, UK, in 2010/2011, and at the University of Wisconsin-Madison, USA, in 2013.
Francesco Cupertino, received the Laurea degree and the PhD degree in Electrical Engineering from Politecnico di Bari, Italy, in 1997 and 2001 respectively. From 1999 to 2000 he was with PEMC research group, University of Nottingham, UK. He is currently Full Professor at Politecnico di Bari, Electrical and Electronic Engineering Department. His research interests include the design of permanent magnet electrical machines, intelligent motion control, and applications of computational intelligence to control

and design. He is the author or co-author of more than 90 scientific papers. He participated and coordinated several research projects mainly founded by companies, Italian Ministry of University and European Union. He is the scientific director of the laboratory Energy Factory Bari (EFB), a joint initiative of Politecnico di Bari and AVIO AERO GE, aimed at developing research projects in the fields of aerospace and energy. He is an IEEE senior member.

11. EMI Issues and Solutions in PWM Converters

Instructors:
Ruxi (Rudy) Wang, GE Global Research Center
Dong Jiang, Huazhong University of Science and Technology

Abstract: Over the past few decades, the goals of power electronics converter design have been to reduce the size, weight, and maintenance, while increasing overall energy efficiency, safety, and reliability especially for modern transportation applications. Electromagnetic interference (EMI) caused by the converter with pulse width modulation (PWM) method has been a big concern for safety and reliability and therefore EMI filter should be designed with the converter to meet the EMI standard. This tutorial provides a fundamental understanding of EMI issues related with PWM converters. The tutorial begins with an introduction of EMI noise source, transition path and EMI load. Power electronics devices and components will be introduced to better understanding the EMI issue from the fundamental layer.

Differential-mode (DM) and common mode (CM) noise definition is derived, with measurement techniques presented. Different noise reduction techniques are presented using multiple PWM converters as example. Compact EMI filter design will be presented considering the filter structure and components coupling. Several practical EMI reduction techniques and construction methods including the modification of PWM method are provided through this tutorial.

The tutorial will cover the following detailed topics: 1) EMI definitions and influence, Noise path with lowest impedance, Circuit equivalents, EMI standard; 2) Fast dv/dt influence to the frequency domain spectrum (challenge for the wideband gap devices), Active device/module equivalent model, Passive component modeling (L, C, cables, stray capacitors, stray inductance, provide few rule of thumb examples); 3) CM, DM Noise Source Definition, Noise Source Calculation and Measurement (Including EMI test setup, LISN, etc); 4) Noise source reduction, Variable switching frequency PWM for EMI Reduction, EMI reduction through noise loop shaping, EMI noise reduction through shielding; 5) Common-mode EMI filter, PWM methods' impact on CM voltage, CM current reduction consideration, CM voltage elimination methods; 6) Passive EMI filter design, Advantages of using active EMI Filter.

Ruxi Wang received the B.S. and M.S. degrees in electrical engineering from Xi'an Jiaotong University, Xi'an, China, and the Ph.D. degree in the Center for Power Electronics Systems (CPES), Virginia Tech, Blacksburg, USA, in 2004 and 2007, and 2012, respectively. In 2012, he joined the Global Research Center of General Electric Company, Niskayuna, USA as a Lead Electrical Engineer. His research interests include electromagnetic interference technology, high-power-density converter design in transportation application, Healthcare electronics, more electrical aircraft system, advanced components and packaging technology. He has published over 40 papers in refereed journals and international conference proceedings and more than 20 awarded or pending patents. Dr. Wang received the William M. Portnoy Award for the Best Paper published in the IEEE Energy Conversion Congress & Expo in 2012.

Dong Jiang received B.S and M.S degrees in Electrical Engineering from Tsinghua University in 2005 and 2007. He began his PhD study in Center for Power Electronics Systems (CPES) in Virginia Tech in 2007 and was transferred to University of Tennessee with his advisor in 2010. He received his PhD degree in University of Tennessee in Dec. 2011. He was with United Technologies Research Center (UTRC) in Connecticut as a Senior Research Scientist/Engineer from Jan 2012 to July 2015. He joined Huazhong University of Science and Technology (HUST) in China as a professor in July 2015. Dong Jiang's major research area is power electronics and motion control, with more than 40 published journal and conference papers and 18 patents/patent applications in this area. He is a senior member of IEEE and associate editor of IEEE Transactions on Industry Applications. He received "Best Poster Presentation Award" in IEEE International Conference on Electrical Machinery (ICEM) 2016 and "Best Paper Award" in IEEE Energy Conversion Conference and Expositions (ECCE) 2016.

12. Wireless Power Transfer for Electric Vehicle and Mobile Applications

Instructors: Chris Mi, San Diego State University

Abstract: Electric vehicles and plug-in hybrid electric vehicles (PEVs) have attracted worldwide attentions because their capabilities to displace petroleum usage and improve energy and environment sustainability. One of the key constraints for the mass market penetration of PEVs is the inconvenience and safety concerns associated with charging. Wireless charging using wireless power transfer (WPT) technology, as an alternative to conductive charging or battery-swapping, can provide the convenience and safety requirements. Recently, EV battery wireless chargers have been realized at large power levels (>100kW) with reasonable sizes, distance in excess of 200 mm, DC-to-battery efficiency of 96.5%, and a misalignment of up to 600 mm, using inductive power transfer technology. This breakthrough will have strong impact on PEVs and a variety of other applications, including consumer electronics, home appliances, medical implant devices, and some industry applications.

This tutorial focuses on the principle and key technical challenges of WPT. It will contain five modules. In module 1, we will provide an overview of wireless power transfer technology and its application in electric vehicle charging. Different terminologies in wireless power transfer will be explained. Various methods for wireless power transfer will be discussed. Magnetic resonance and compensation methods will be introduced. In module 2, we will discuss the principle, theory, analysis methods, and applications of inductive wireless power transfer technology. Various types of coil design for maximum coupling coefficient, including circular, rectangular, flux pipe, double D, and DDQ coils. Measurements of coil inductance will be discussed. It will be aimed at novel designs that considerably reduce size and cost while increase coupling coefficient and system efficiency. A double sided LCC resonant converter topology for the resonant will be discussed in detail. In module 3, the presentation discusses capacitive power transfer (CPT) for EV charging applications. A double-sided LCLC compensated topology and its design process will be discussed in detail. The design of a 2.4kW CPT system with four 610mm × 610mm copper plates and an air gap distance of 150mm will be shown with a 90.8% efficiency. Module 4 briefly discuss the power electronics circuits for WPT systems, such as AC-DC, DC-DC, and DC-AC. The last module will discuss other aspects of wireless chargers, such as safety issues, switching frequency band requirement, SAE WPT J2954 standard, object detection methods, communication methods between transmitter and receiver, some testing results of foreign object inserted between the transmitter and receiver exist.

Chris Mi is a fellow of IEEE, Professor and Chair of the Department of Electrical and Computer Engineering, and the Director of the US DOE funded GATE Center for Electric Drive Transportation at San Diego State University, San Diego, California, USA. He was previously a professor at the University of Michigan, Dearborn from 2001 to 2015. Previously he was an Electrical Engineer with General Electric Canada Inc. He was the President and the Chief Technical Officer of 1Power Solutions, Inc. from 2008 to 2011. He is the Co-Founder of Gannon Motors and Controls LLC and Mia Motors, Inc. He has taught tutorials and seminars on the subject of HEVs/PHEVs for the Society of Automotive Engineers (SAE), the IEEE, workshops sponsored by the National Science Foundation (NSF), and the National Society of Professional Engineers. He has delivered courses to major automotive OEMs and suppliers, including GM, Ford, Chrysler, Honda, Hyundai, Tyco Electronics, A&D Technology, Johnson Controls, Quantum Technology, Delphi, and the European Ph.D School. He has offered tutorials in many countries, including the U.S., China, Korea, Singapore, Italy, France, and Mexico. He has published more than 100 articles and delivered 30 invited talks and keynote speeches. He has also served as a panelist in major IEEE and SAE conferences. Dr. Mi is the recipient of "Distinguished Teaching Award" and "Distinguished Research Award" of University of Michigan Dearborn. He is a recipient of the 2007 IEEE Region 4 "Outstanding Engineer Award," "IEEE Southeastern Michigan Section Outstanding Professional Award." and the "SAE Environmental Excellence in Transportation (E2T) Award." He was also a recipient of the National Innovation Award and the Government Special Allowance Award from the China Central Government. In December 2007, he became a Member of Eta Kappa Nu, which is the Electrical and Computer Engineering Honor Society, for being "a leader in education and an example of good moral character."