FREEDM SYSTEMS CENTER

Annual Research Symposium
April 10-12, 2019
Duke Energy Hall, Hunt Library

| **Wednesday, April 10** |
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| **Tutorial 1: Designing WBG Solid-State Circuit Breakers for Ultra-Fast Transient Protection**<br><br>Advancement in ultra-low impedance battery storage and in WBG power electronic systems has rendered conventional circuit protection simply too slow. This seminar gives an in-depth exploration of Solid-State Circuit Breaker (SSCB) technology for Low and Medium Voltage systems and introduces a design approach to guide the practitioner in addressing ultra-fast transient protection. Special attention is given to both electrical and thermal energy absorption during a short circuit event. Attendees will review an SSCB design example utilizing a 6.5kV/100A/50ns WBG switch.<br><br>Presenters: Doug Hopkins, Bahji Ballard, Utkarsh Mehrotra |
| **Tutorial 2: Microgrid Hierarchical Controls**<br><br>This tutorial covers the components and devices, system architectures and controls, ancillary services and grid support, and customer interactions and benefits in the context of microgrids and networked power electronics based systems. This tutorial begins with an overview of the basic power electronics components in a modern power system, and then presents system architecture, stability issues, primary and secondary control, grid synchronization techniques, and interconnection standards for DERs. Enabling communication technologies and few case studies are also presented. Finally, the tutorial will conclude with trends into the future for widespread industrial adoption.<br><br>Presenters: Srdjan Lukic, Iqbal Husain, M A Awal, Hui Yu |
| **Thursday, April 11** |
| **Keynote 1: Batteries and Electrification R&D**<br>Steven Boyd, US Department of Energy |
| **Keynote 2: Building a Sustainable and Resilient Grid by Controlling the Edge**<br>Sonja Glavaski, The Faraday Grid<br><br>The evolution of the electric grid faces significant challenges if it is to integrate and accept more energy from renewable generation and other Distributed Energy Resources (DERs). To maintain reliability and turn intermittent power sources into major contributors to the energy mix, we have to think about the grid differently and design it to be smarter and more flexible. This talk will identify opportunities in developing next generation control technologies and grid operation paradigms that address these challenges and enable efficient, sustainable and reliable transmission and distribution of electrical power. |

**FREEDM Updates**
Iqbal Husain, Srdjan Lukic, Ning Lu

**Session 1A: Power Devices and Packaging**

NCSU Breakthroughs in SiC Power MOSFET Technology, Jay Baliga
This presentation will cover recent work on creating a 'national process' for manufacturing SiC power devices at a 6 inch foundry and on enhancing the performance of SiC devices to encourage market penetration. Topics covered include PRESiCE, Inversion Channel and Accumulation Channel for SiC power MOSFETs, the JBSFET with integrated Schottky diode, JFET optimization, and the BiDFET, a monolithic bi-directional field effect transistor.

Accelerating Commercialization of SiC Power Electronics, Victor Veliadis
Silicon power devices have dominated power electronics due to their low cost volume production, excellent starting material quality, ease of processing, and proven reliability. Although these power devices continue to make significant progress, they are approaching their operational limits primarily due to their relatively low bandgap, high conduction and switching losses, and poor high temperature performance. This presentation will highlight the favorable material properties of Silicon Carbide (SiC) devices, and discuss application opportunities such as "more electric aerospace" with weight, volume, and cooling system reductions; automotive power electronics; more efficient, flexible, and reliable grid applications; variable frequency drives for efficient high power electric motors; and novel data center topologies.

GaN and Ultra Wide Bandgap III-Nitrides for Power Electronics, Spyridon Pavlidis
Galllium nitride (GaN) technology has already achieved commercial successes in lighting and telecommunications, and is now rapidly making headway into the power electronics market. This presentation will discuss the merits of GaN for power devices, both vertical and lateral. Recent advances towards technological milestones, such as ion implantation, will be discussed. Methods that leverage the unique polar nature of GaN to push performance limits and realize new devices will also be explored. Lastly, the prospects of ultra wide bandgap III-Nitrides, such as AlN, will be presented.

**Session 1B: Power Systems**

Stochastic Distribution Controls for Minimizing Uncertainties Impact for Complex Systems, Hong Wang
Stochastic distribution control theory controls the probability density function shape for variables in dynamical stochastic systems with applications in modeling, signal processing, optimization and data mining. However, the operation of complex systems are increasingly affected by randomness and uncertainty. Examples include intermittent power from renewable resources and variable material quality in process industries. This presentation will review the background of stochastic distribution control and its application.

Toward a Carbon Free Energy Supply – Insights from the City of Los Angeles, Don Morrow
California recently approved SB-100 which accelerates the timeline for renewable integration. New targets are 60% by 2030 and 100% by 2045. Not to be outdone, New York's Green New Deal requires 70% by 2030 and 100% by 2040. Los Angeles, the second largest city in the US, is investigating how to replace natural gas with renewable energy and energy storage to ensure full compliance with NERC and WECC reliability standards and with Los Angeles Department of Water and Power planning and operating criteria. This presentation will share this analysis and insights into successful integration of large amounts of renewable energy resources.

The Evolutionary Market Structure in the Smart Grid Era, Wenyuan Tang

Smart grids contribute to a sustainable future yet impose challenges for power system operation and electricity market design. Meanwhile, big data brings opportunities for the management of future energy systems. This talk will introduce applications of economic theory in the analysis and design of market mechanisms. It will also present data analytic methods such as machine learning for gaining deeper insights. Finally, Dr. Tang will review ongoing projects to show how market structures for transmission and distribution may evolve in the near future.

Analytics in the Digital Utility, Arnie de Castro, SAS
Anyone who has done utility load forecasting, state estimation or resource optimization has employed in some form what we now call analytics. However, it is the deluge of data from meters, sensors and devices, and the convergence of information and operations technologies in an increasingly connected grid that provides a challenge and an opportunity for the industry to rethink the way it views analytics. This presentation will consider utility applications of analytics to manage the abundance of data, provide better customer care, improve operations and reduce costs in the increasingly digitized grid.

Advancing the Cyber Security of Power Grids, Reynaldo Nuqui
This presentation will show technologies from DOE-funded research projects related to defense-in-depth cyber security of energy delivery systems using domain principles. The technologies are geared towards electrical substations. They leverage the physics of these systems to evaluate the cyber security of incoming commands and measurements.

**Session 2A: Microgrids and Renewables**

Leveraging DER's with Prosumer Microgrids, Andy Haun, Schneider Electric

Impacts of Distributed Generation - Current and Future Challenges, Trent Miller and Brian Dale, Duke Energy

Residential Microgrids, Jim Musilek, NCEMC
This presentation will provide background on the projects that have been completed by North Carolina's Electric Cooperatives and focus on a neighborhood microgrid that is currently under development. The microgrid discussion will highlight the components and technical hurdles overcome to bring this project from concept to reality.

Enabling High Penetration of Distributed PV through the Optimization of Sub-Transmission Voltage Regulation, Ning Lu, NC State

**Session 2B: Power Electronics**

Digital Twin Validation for Distributed Resource Converters, Johan Enslin, Clemson University
The increased use of variable and intermittent renewable generation and increased requirements for reliability and resiliency in the power supply has increased the importance for validating Distributed Resource converter performance. Furthermore, distributed generation, MicroGrids and Grid-Edge devices are not visible on the utility's operation and control centers. This presentation will discuss the validation efforts to develop Digital Twins for renewables, energy storage, and GridEdge converters.

Applications for Wide Bandgap devices – perspectives from ABB, Sandeep Bala, ABB
The presentation will discuss applications and challenges for integrating wide bandgap devices in ABB products. Examples of products and R&D demonstrations using SiC and GaN devices will be shown.

Mike Mazzola, UNC Charlotte

Grid Modernization Enabled by SiC Device based SSTs and Innovations in Medium Frequency Magnetics, Subhashish Bhattacharya, NC State

**Friday, April 12**

**Future of the Power Grid**
Marija Ilic, MIT

As the electric grid evolves to incorporate more DER, more EVs, and more microgrids, control will become much more complex. Researchers are not adequately integrating industry needs in order to reduce risk and increase the value of their work. Of course, the additional data from new sensors holds the promise of enhanced performance but also the peril of overwhelming communication channels. Sounds like a big mess! This presentation will discuss applications of complexity theory and propose a return to basic physics and intuitive modeling to create the next generation electric grid.

**Towards a Resilient Information Architecture Platform for Smart Grid**
Gabor Karsai, Vanderbilt

Smart Grid functions like protection, autonomous energy management, remedial action schemes, and microgrid control need not only intelligent algorithms but also a robust, secure, and decentralized software platform that enables timely decision making and control. Such a platform would act as an operating system for grid applications. By necessity, the applications have to run close to the physical system, as the roundtrip delays to the cloud are not affordable. Our team is developing such a platform with novel capabilities that allow the development and operation of resilient, distributed, real-time applications that must exhibit a very high degree of dependability.

**Where Ohm's Law Meets Moore's Law: Open Source to Accelerate the Energy Transition**
Shuli Goodman, LF Energy

The digitalization of energy will remake the grid to resemble a mesh network or a system of systems that looks more like the Internet. What can we learn about the adoption of open source in the scaling of other industries such as telecommunication, automotive, platform businesses, and now energy? The global challenges we face are formidable to remake our energy systems and decarbonize our economies. This overview will explore the history of open source, what the Linux Foundation has learned about shared technology innovation, and provide examples with applications to the electrification of everything.

**Session 3A: Circuit Protection and Controls**

DC Circuit Protection for the US Navy, Patrick McGinnis, Naval Surface Warfare Center
This presentation will explain the impetus for the Navy's emerging DC circuit protection requirements, detail the development work accomplished to date in the 1kV, 1kA arena, and conclude with a summary of future efforts aimed at transitioning the 1kV device to shipboard applications and developing a next generation 12kV, 2kA unit.

Fast Circuit Protection for Next Generation Systems and Apparatus, Debrup Das, ABB
System protection built on arc-based solutions has largely been unchanged in the last century. However, the power delivery system is transforming rapidly. More "native DC" loads and sources, such as electric vehicles, solar PV, and battery energy storage systems are posing new challenges. Breakthroughs in semiconductor technology promise alternative protection solutions for the future.

Enabling an Intelligent Solid State Circuit Breaker, Mike Harris, Atom Power
The recent performance and reliability improvements of WBG devices has enabled the realization of a commercially viable Solid State Circuit Breaker (SSCB). Present day WBG devices provide a level of performance sufficient to meet the power delivery and thermal requirements for a SSCB. Disrupting the existing thermal-magnetic circuit breaker market will take a focus beyond WBG data sheet parameters and require a deeper understanding of system functionality. This presentation will cover the key factors required to support market acceptance of SSCB technology. Critical areas for consideration are product cost, reliability, compliance to product safety standards and delivering system features with a focus on usability.

SiC JFETs for circuit protection, Anup Bhalla, United Silicon Carbide
SiC JFETs allow users to exploit the excellent properties of 4H-SiC to fashion previously unattainable solutions to a wide range of circuit protection functions. We will discuss product examples for <1200V solid state breakers, current limiters and load switches, to higher voltage options scalable to 10 and 30KV. The physics of JFETs that allow stable operation under controlled low dV/dt switching and their excellent current limiting behavior will be discussed.

**Session 3B: Controls for Next Generation Power Systems**

Low-inertia Grids and the Role of Oscillator-based Controllers, Brian Johnson
Renewable resources and storage technologies are interfaced to the grid through power electronics inverters. These energy conversion interfaces are fundamentally different from synchronous generators in that they have no rotational inertia and are generally much smaller in power rating. One can hypothesize that future power systems will have: i) low(er) mechanical inertia, and ii) many (more) actuation nodes. Ensuring stable and reliable operation of such a system will be contingent on scalable models that capture the networked interactions of many inverters and few conventional generators. This talk will outline techniques for obtaining reduced-order models that capture the dynamics of large numbers of inverters and describe how such models will be critical to analyze the next-generation power grid.

Optimal Anomaly Detection and Dispatch Response in Transportation Networks, Abishek Dubey
Much of the research on smart transportation systems has focused on optimal route planning for congestion reduction. However, optimal incident response and anomaly detection are also crucial challenges. This presentation will highlight the development of a decentralized rapid anomaly framework and a holistic approach for effective emergency response by predicting when and where incidents happen and understanding the changing environmental dynamics. Together, this framework describes a system that collectively deals with dynamic transportation problems with models that are updated via streaming data sources.

Challenges and Opportunities Introduced by IEEE Std 1547-2018, Kevin Chen, Duke Energy
The control of DERs will be a key concern for grid safety and reliability for next generation power systems. IEEE 1547-2018 defines the interconnection and interoperability requirements for DER to provide specific grid supportive functions. These new requirements will bring challenges and opportunities to power system operation and control.

Passivity-Based Globally Stabilizing PI Controller, Aranya Chakrabortty, NC State
Proportional-Integral (PI) control is a commonly used mechanism for regulating power flows in distribution systems. Such controls, however, come at the cost of guaranteeing only local stability, meaning that as the system load changes the controller gains must be tuned in order to maintain stability of the primary control loop. This issue can be resolved with an alternate PI controller that uses the passivity property of solid state converters. This presentation will demonstrate this approach using a networked microgrid model with three power converters and various communication topologies.