Third eGrid Workshop Maps the Grid of the Future

Attendees engage to examine the role of power electronic applications in modern electric power systems

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Digital Object Identifier 10.1109/MPEL.2018.2886710
Date of publication: 19 February 2019

Distributed energy resources (DERs), bulk grid events, grid stability and resilience, microgrids, standards, power quality, and high-voltage dc (HVDC) technologies were among the topics of interest at the third IEEE International Workshop on Electronic Grid (eGrid). IEEE eGrid 2018, hosted by Clemson University in Charleston, South Carolina, 12–14 November 2018, provided a platform for examining the role of power electronic applications in modern electric utilities. Power electronics is currently changing from an enabling technology for renewable generation and energy efficiency to an underpinning technology for grid modernization, electronic transmission, and distribution grids that can effectively manage electricity among many power

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electronic-based sources and loads. Power electronic-based sources and loads will be prominent in the grid of the future.

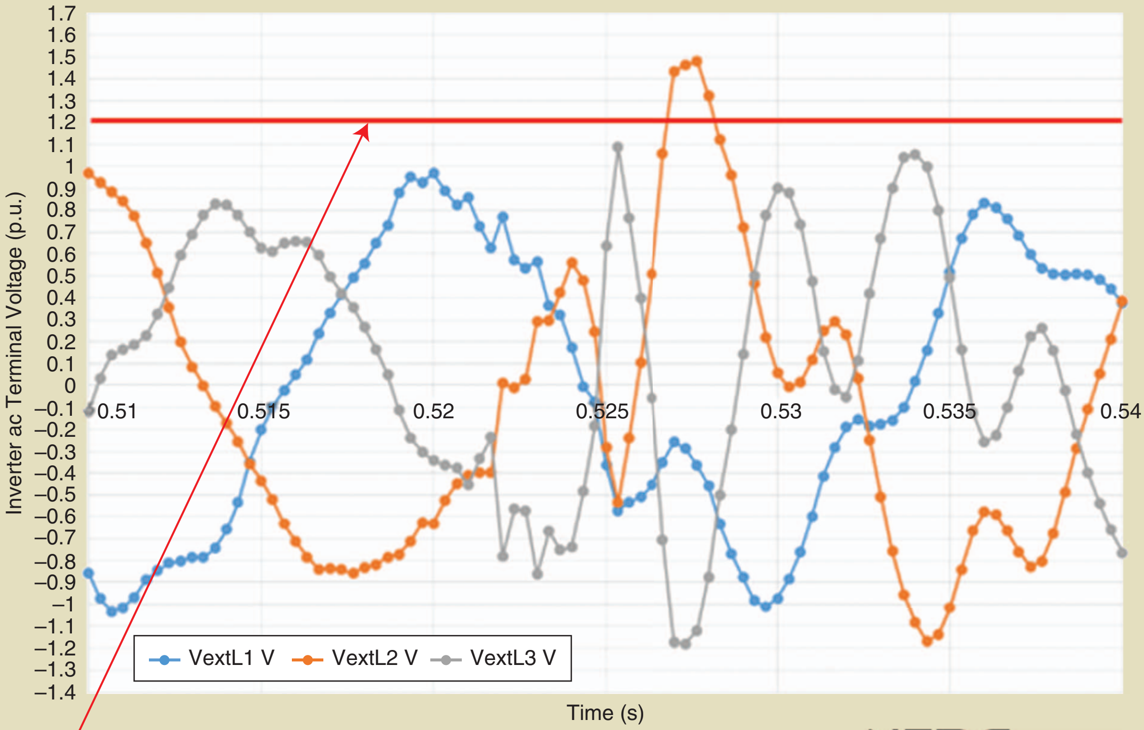
eGrid is organized jointly by the IEEE Power & Energy Society (PES) and the IEEE Power Electronics Society (PELS). These two Societies established eGrid as a forum for industry representatives, business leaders, researchers, engineers, and students in the fields of power electronics and power systems to present and exchange ideas on how to effectively integrate power electronics to create smarter and more efficiently managed power grids.

The technical program started with four selected tutorials on Monday, 12 November. In the morning, Jinjun Liu of the Xi'an Jiaotong University Electrical Engineering School in China presented "Non-Communication Coordinative Control of Distributed Energy Source Converters in an Electronic Power Grid." Parallel to this session was "DER Hosting Capacity Analysis and T&D Integrated Planning Using PSS©SINCAL," which was presented by Wayne Dias of Siemens and Sam Copeland of Ameren. The last two, also simultaneous tutorials, were "Small-Signal Modeling and Stability Analysis of Grid-Connected Power Converters," presented by Xiongfei Wang of Aalborg University and Rolando Burgos of Virginia Polytechnic Institute and State University, and "IEEE 1547-2018 Revision and Smart Inverters," presented by Aminul Huque of the Electric Power Research Institute (EPRI). The afternoon was spent touring the Boeing assembly plant and the Clemson University Restoration Institute campus buildings and test laboratories. A welcome reception overlooking the Cooper River and Charleston Harbor was held at the Clemson University Zucker Graduate Education Center.

Keynote and Invited Sessions

Tuesday, 13 November, began with a keynote address by Siemens' Mike Carlson. His talk was "Is an Integrated Digital Grid a Nice-To or Must-Have for the Industry?" This address was followed by Plenary Panel 1, "Reliability in eGrid With High Penetration Inverter-Based Energy Resources: Challenges and Opportunity With Technology Advances." The panel was chaired by Damir Novosel of Quanta Technology. The first speaker, Ryan Quint of the North American Electric Reliability Corporation (NERC), talked about bulk grid events involving solar photovoltaic (PV) inverters, such as the events associated with the Blue Cut Fire and Canyon 2 Fire (Figure 1). In the Blue Cut Fire, the frequency dropped to 57.5 Hz, and 1,200 MW of PV generation was tripped. In the Canyon 2 Fire, inverters tripped on an 8% voltage sag for one cycle. The NERC has operating guidelines only on generators rated greater than 75 MW. Next, Gary Kobet of the Tennessee Valley Authority described some effects of inverter-based generation on bulk power system dynamics and short-circuit performance. Babak Enayati with National Grid discussed the impact of the IEEE 1547 standard for DER interconnections on smart inverters. The newly revised standard attempts to address the dynamics of volt/volt-amp reactance support, power quality, flicker, overvoltages, grounding, and unintentional islanding. The panel concluded with Andrew Isaacs of Electranix discussing issues caused by low short circuit strength systems. Low short circuit power ratings lead to ride-through failures and small signal oscillations.

Invited Session 1, "PV and Wind Converters," was chaired by Xiongfei Wang of Aalborg University and began with Rik De Doncker of RWTH Aachen discussing the lower costs and higher efficiencies of large dc collector fields for offshore wind installations. Next, Curtiss Fox of Clemson University discussed the testing and standardization of converters for distributed generation and the work taking place at the Energy Innovation Center on Clemson's Charleston campus (Figure 2). Allen Hefner with the U.S. Department of Energy (DOE) discussed the higher efficiencies and added grid support functions provided by wide-bandgap power electronics. These benefits will be extremely important as renewable penetration increases from <20% today to



Instantaneous Voltage (p.u. Nominal Peak)	Samples	Time (s)	Cycles
> 1.1	5	0.00167	0.1
> 1.2	4	0.00133	0.08
> 1.3	4	0.00133	0.08
> 1.4	3	0.00100	0.06

NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

FIG 1 **The data and a graph related to bulk grid events involving solar PV inverters. The image relates to the presentation "Reliability in eGrid with High Penetration Inverter-Based Energy Resources: Challenges and Opportunity with Technology Advances" by Ryan Quint of the NERC. The data shown relate to bulk grid events associated with the Canyon 2 Fire. (Image courtesy of NERC.)**

possibly >100% in the future. Aminul Huque with EPRI discussed the interactions of several smart inverters operating in parallel that shut off after system faults occurred. Next, Razvan Panati of Siemens discussed the added efficiencies provided by smart hybrid inverter technology. Barry Mather of the National Renewable Energy Laboratory (NREL) concluded the session with a presentation about renewable energy interconnections at the intersection of power electronics and power systems. More standards are under development aimed at the operational aspects of renewable generation connected to the power grid.

During the lunch period, Bruce Walker (Figure 3), assistant secretary of the DOE, gave a talk, "Grid Modernization in an Ever-Changing Environment." He described the DOE's efforts to make the U.S. grid more resilient through major grid modernization initiatives and workforce development efforts. He also referred to new DOE funding opportunities in grid resiliency and reliability.

After lunch, Invited Session II took place, moderated by Russell Desalvo of ComEd Chicago. Five speakers addressed the topics of energy storage and microgrids. John Schaaf from ConEdison Battery Storage discussed market trends in energy storage that point to continued growth in the industry. Bert Taube from Southern Research described utility-scale energy-storage systems in the field and delved into the role of testing and lowering the risk of deployed energy storage. Jim McDowall from Saft America described three case studies of the use of battery energy storage in conjunction with renewables to achieve fuel savings. These case studies involved remote communities in Alaska and northern Canada, which typically rely on electricity generated by diesel engines. The high cost of delivering fuel to the communities makes electricity there very expensive. Danny Kassis from Scana Corporation discussed the efforts of utilities and their commercial and industrial customers to evaluate the current utility business model and improve technologies to increase reliability and efficiency. He pointed out that microgrids are becoming an important tool for increasing security and resiliency and are a key link to the success of energy storage, the next logical iteration in the energy-delivery business model. Finally, Alex Rojas from Ameren Services

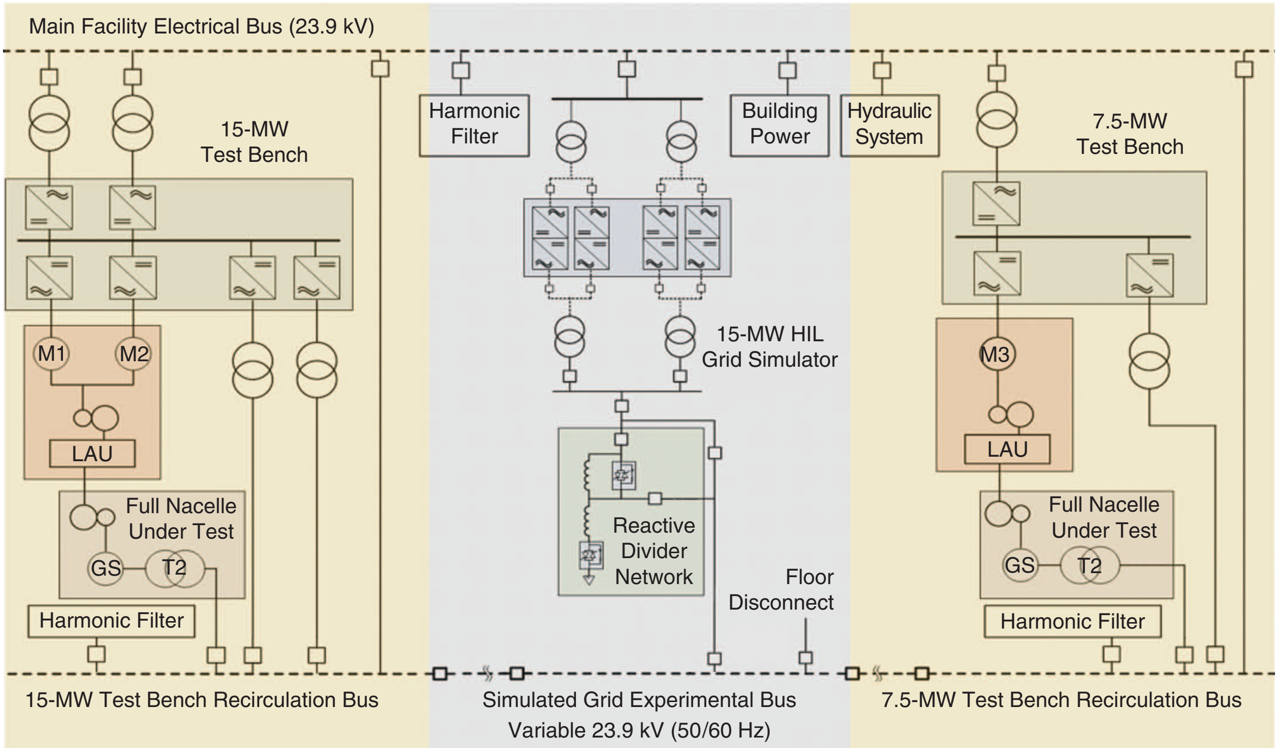


FIG 2 A single-line diagram of the South Carolina Electric & Gas Energy Innovation Center. The image relates to discussion by Curtiss Fox of Clemson University of work taking place at the center. (Image courtesy of Clemson University). LAU: load application unit; HIL: hardware in the loop.

shared his ideas about demand-side management strategies for the modern utility.

Dushan Boroyevich of Virginia Polytechnic Institute and State University chaired Invited Session III, "HVDC and FACTS." The first speaker, Ram Adapa of EPRI, presented "The Role of HVDC and FACTS in the Future Smart Electric Grid." He discussed power electronics, a key component of the smart grid, with applications affecting generation, transmission, and distribution systems. He also talked about EPRI's history and current activities in such technologies as solid-state transformers and flexible ac transmission systems (FACTSs). Around the world, activities related to HVDC technology are increasing as developers discover how to employ HVDC technology to integrate remote wind and solar energy systems into the power grid. With new developments in dc grids and dc breakers, future capacity increases with wide-bandgap semiconductors are anticipated. The second speaker, David Roop from Dominion Energy, presented the talk, "FACTS: Flexibly Solutions for a Changing Grid." Dominion is studying and implementing power electronics-based FACTS. The company sees six specific FACTS applications, classified as foundational and emerging opportunities. FACTS can effectively manage the variability of renewable energy sources, and mobile static synchronous compensator devices provide significant benefits in outage management (Figure 4).

Next, Rainer Marquardt of the Universität der Bundeswehr München presented "Multi-Terminal-DC-Grids: Future Requirements for the Converters." The fundamental requirement of future dc grids will be high availability, he said. Power electronic technology now exists to create dc grids in parallel with ac grids. This technology requires fast fault clearing and effective fault management. Fault behavior is heavily influenced by passive dc-side capacitance; therefore, controllability of modular multilevel converters

FIG 3 Bruce Walker, assistant secretary of the U.S. DOE, gave the talk, "Grid Modernization in an Ever-Changing Environment." He described the DOE's efforts to make the U.S. grid more resilient. (Photo courtesy of Johan H. Enslin.)

(MMCs) offers a big advantage. Full-bridge converters offer fault performance like that of line commutate converters, with the additional benefits of fast reactive power control.

The last speaker for this session, Richard Zhang of GE Power, presented "Towards Grid of Future—Recent Innovations & Challenges." The transmission grid is evolving at an accelerating rate. GE's investments in HVDC technology include expanded offices and a factory, a simulator laboratory, and an HV test laboratory (Figure 5). The 900-MW DolWin3 offshore wind transmission link, which uses GE HVDC voltage source converters, has reached 700 MW and awaits completion of the wind farm to reach full power. New MMC technologies are being explored, such as series-bridge converters. Meanwhile, medium-voltage dc technology is becoming more practical and attractive, and the Angle project in the United Kingdom is under construction to convert an ac circuit to dc operation.

The second day of IEEE eGrid 2018 concluded with a wrap-up session. The discussion revolved around the question of increasing the use of power electronics in today's power systems. It was pointed out that the laws of economics and physics will

FIG 4 Four photographs showing FACTS equipment, including a cooler bank, converters, and reactor trailer. The photographs are related to the presentation by David Roop of Dominion Energy titled "FACTS: Flexibly Solutions for a Changing Grid." (Photos courtesy of Dominion Energy.)

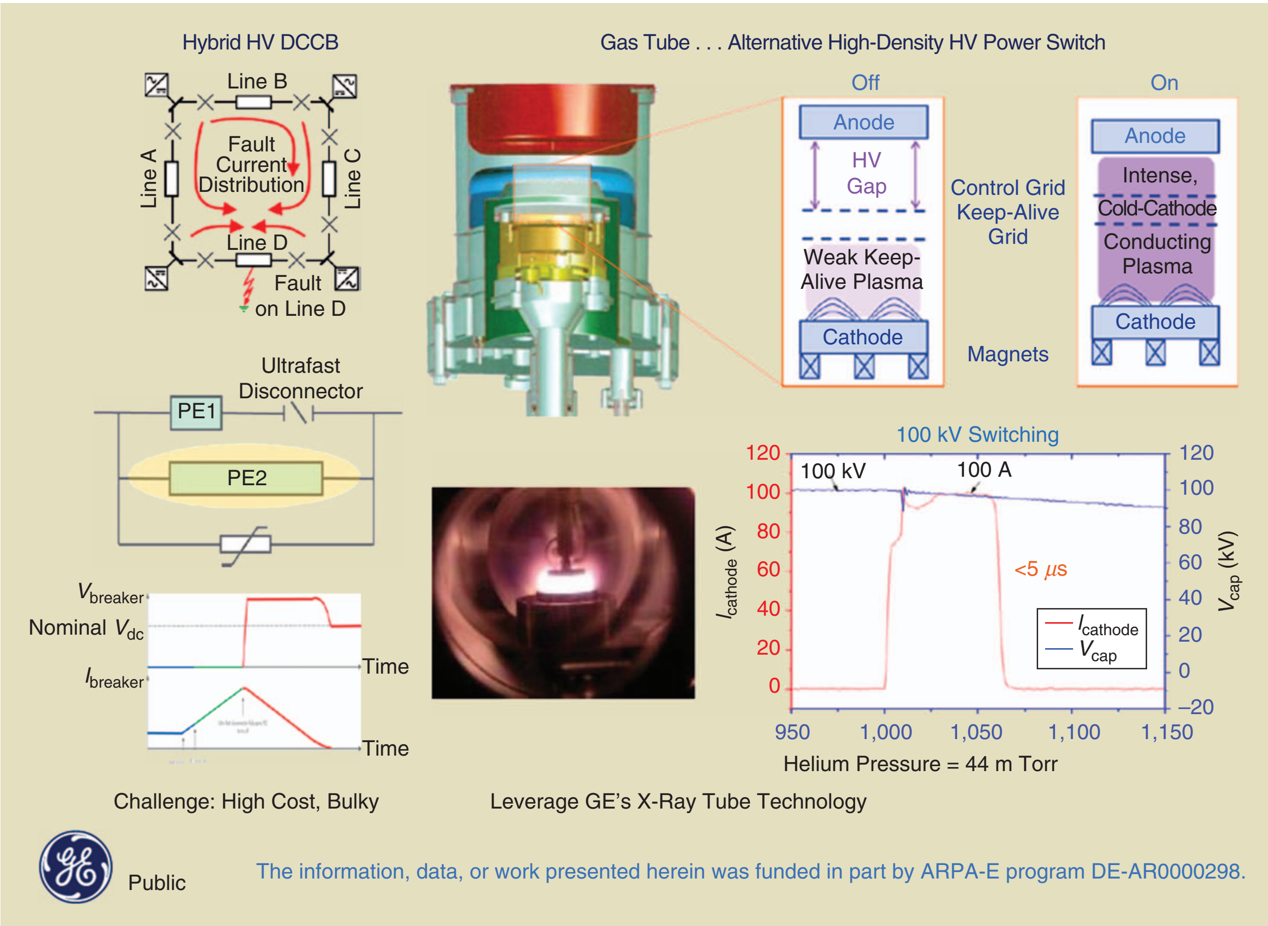


FIG 5 A photograph and various diagrams and graphs related to the talk by Richard Zhang of GE Power: "Towards Grid of Future—Recent Innovations & Challenges." DCCB: dc circuit breaker. (Images courtesy of GE.)

reach an "equilibrium" state. Projects funded by the DOE, given high visibility, can help increase investments from manufacturers and vendors in power electronic-based technology and give decision makers and regulators the knowledge they need to make sound decisions. Meanwhile, technology and concern for the environment will drive customer behavior, which will ultimately shape regulation and infrastructure. In either case, the regulatory environment needs to benefit all stakeholders, even if the benefits are not huge. It was also mentioned that new material, such as silicon carbide, has been increasingly deployed at the 1,700-V level and will soon perform at higher voltages. Wednesday, 14 November, began with a keynote address by Melisa Johns of Duke Energy. Her talk focused on "Growing Customer and Operational Value Through Emerging Grid Solutions."

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Grid Modernization Initiatives

The keynote speech was followed by Plenary Panel II, "Grid Modernization Initiatives," which included six presentations:

- "U.S. Department of Energy Grid Modernization Initiatives," by Kerry Cheung, Office of Electricity, DOE
- "Solar to Step Up Its Grid Services Game," by Guohui Yuan, Solar Energy Technologies Office, DOE
- "The Politics of Grid Modernization," by Bret J. Sowers, Southern Current LLC
- "Integrating DERs: A Partnership Between Customer and Grid Functions," by Cat Wong, Entergy Services LLC
- "NSF's Perspective on Cybersecurity and Renewables Integration in the Digital Grid," by Anil Pahwa, National Science Foundation
- "Electric Power & Manufacturing Technology Futures," by Mark Johnson, Clemson University.

Today, electricity meets 40% of the total energy needs of the United States in the residential, commercial, industrial, and transportation sectors. When renewable power generation costs reach the "shut-down" parity (i.e., the marginal operation expenses of the incumbent technologies), the electricity landscape will be permanently and drastically changed. This prospect has set the stage for grid modernization initiatives on all fronts—technological, market, and policy. These initiatives will affect everyone associated with the industry, including electricity producers, regional transmission organizations, independent system operators, local distribution companies, electricity consumers, policy makers, and regulators. Most of the states in the United States have been more active in setting policies than in offering financial incentives for grid modernization through legislative or regulatory actions. The grid modernization initiatives in the United States are coordinated at the Office of Energy of the DOE with an aggressive and urgent five-year strategy and are supported by the Energy, Power, Control, and Networks Program of the National Science Foundation. The grid modernization initiatives cover the major areas of devices and integrated systems, system operations and control, security and resilience, sensing and measurement, and design and planning tools.

Utilities, funding agencies, and customers have identified the integration of DERs in grids as a key issue. DERs present opportunities for both grid operators (generation, transmission, distribution, and grid modernization) and customers (residential, commercial, and industrial), with the potential to affect customer satisfaction as well as to provide safe, affordable, and reliable power. However, DERs are being developed and operated without full knowledge of the impact they are having on the grid. Meanwhile, data for modeling DERs are inadequate and processes for interconnection are not automatic. To address these issues, the industry needs support and collaboration to design, develop, and implement better DER-related processes, procedures, standards, and systems. PV systems can be used to provide grid services in addition to producing electricity. NREL, the California Independent System Operator, and First Solar have conducted a demonstration project on a 300-MW utility-scale PV power plant in California to test its ability to provide a wide range of ancillary services to the electric grid. These grid services include spinning reserves, load following, voltage support, ramping, frequency response, variability smoothing, and frequency regulation.

The DOE has initiated the Solid-State Power Substations (SSPS) project, which will strategically integrate power converters within substations. The project's planners intend to use modular, scalable, and adaptable power electronic building blocks to achieve economies of scale. While the concept behind the SSPS project isn't new, the timing is right because of this community and the deployment of many different power converter systems. SSPS technology will start with low-voltage residential, commercial, and industrial systems (SSPS 1.0) and will expand to medium-voltage and medium-power systems, including HVDC systems and microgrids, with integrated communications and coordination (SSPS 2.0). The end goal is a scalable, adaptable, cost-effective, and flexible ac/dc power router in all voltage levels (SSPS 3.0).

Invited Session IV, "Advancing Grid Resiliency via Interoperable Distribution Automation (DA) and DER Solutions," began with "Flexibility as a Resiliency Resource," a talk by Kevin Schneider of the Pacific Northwest National Laboratory. He spoke about a project to increase distribution system resiliency using flexible DER and microgrid assets enabled by the Open Field Message Bus. That effort is part of the DOE Grid Modernization Laboratory Consortium. The project team includes large national laboratories, utilities, universities, industry representatives, and the Smart Electric Power Alliance. The objective is to accelerate the deployment of resilient and secure distribution concepts through the flexible operation of traditional assets, DERs, and microgrids.

Next, Kevin Fox of Duke Energy delivered the talk, "Addressing a Two-Way Power Flow Future With a Self-Optimizing Grid Strategy." Duke Energy will be investing US$25 billion over 10 years in an advanced metering infrastructure and in technologies to reduce outage frequency and duration by 50%.

The ORNL is prototyping platforms and has microgrid and nanogrid concepts.

Mark Buckner of the Oak Ridge National Laboratory (ORNL) presented "An Open Source Microgrid Controller Demonstrated on a Software-Defined Grid Research Test Harness." The ORNL is prototyping platforms and has microgrid and nanogrid concepts. The laboratory works in a highly regulated industry that requires the laboratory to quickly validate concepts in the field. The SI-GRID platform is a flexible and reconfigurable three-phase 24-V ac research and development platform. The Complete System-Level Efficient and Interoperable Solution for Microgrid Integrated Controls is an open-source research framework for advanced power system functions. The last piece is the Digital Twin, a virtual system of a physical asset equipped with line emulators using Typhoon hardware-in-the-loop (HIL) testing software. The last speaker for this session, Murali Baggu with NREL, spoke about "Distributed Energy Resource Management Systems (DERMS)—Lessons Learned From an ADMS Testbed." He described the components of the advanced distribution management system (ADMS) testbed at NREL. The components are software packages control HIL (CHIL) and power HIL (PHIL). Another piece is remote HIL to connect to other (test) facilities. The project requires advanced visualization for integrated data collection and management using the same protocols employed in the real world. Several test cases were presented.

In Invited Session V, "Application of Real-Time Simulation and HIL Testing (RT-HIL Testing) in Power Systems," three vendors and two customers made presentations. The first was "Evolution of Hardware in the Loop Simulation," by Aniruddha Gole of the University of Manitoba. HIL testing was presented as a powerful and safe approach for testing and debugging power hardware without connecting it to an actual network. The presentation covered the evolution of HIL, from early approaches using analog computers, to real-time digital simulators for CHIL testing, and, finally, to the recent introduction of PHIL simulation. In his talk, "Recent Developments for Power Hardware in the Loop Simulation on the RTDS Simulator," Christian Jegues of RTDS Technologies, described PHIL simulation, which involves the real-time simulation environment exchanging power with real, physical power hardware, such as renewable energy hardware, electric vehicles, batteries, motors, and loads. An important issue is the fidelity of the interface between the RTDS Simulator and the device being tested in maintaining the accuracy and stability of the simulation results.

Jean-Nicolas Paquin of Opal-RT Technologies presented "Real-Time Simulators as a Key Technology for Future Power Systems Equipment Testing." He described how real-time simulator-based testbeds will have a significant role in ensuring reliable control and protection of electric equipment and power grids. Electrical systems are experiencing a shift in the operating philosophy away from conventional centralized energy production and toward distributed power generation with the ability to island parts of the system. These concepts will improve resilience to system failures or faults but only if a proper cybersecure communication, control, and protection backbone is in place.

Next, Maigha of ComEd Chicago delivered a talk "Microgrid Master Controller for Integrated Solar-Storage Applications." ComEd has developed an advanced microgrid master controller capable of managing a cluster of two or more microgrids. The master controller establishes communications with microgrid assets, controls various elements, such as smart inverters and controllable generation, and performs distribution automation. The controller is based on a hierarchical structure with primary, secondary, and tertiary controls. The last presentation for this session was "Evaluating PV Inverter Impact on Distribution Protection and Automation Schemes in RT-HIL Environment," by Amin Salmani and Sergio Flores Castro from San Diego Gas & Electric. This presentation covered the utility's experience with a very high penetration of DERs. The utility has conducted hosting capacity studies as part of its integrated distribution planning studies. Hosting capacity studies are normally focused on the investigation of voltage issues and thermal capacity limits. Because planning tools may not be able to provide a precise modeling of various aspects of the control, protection, and automation schemes, research is scant on the impact of high PV-system penetration on conventional protection and automation schemes of distribution systems.

Three electronic poster (e-poster) sessions were held throughout the day on Wednesday. They covered all accepted papers and presentations submitted to the workshop. IEEE eGrid 2018 received 57 full-paper and 12 presentation submissions, of which 37 papers and 10 presentations were accepted for the electronic poster. All presenters attended the workshop. Each presenter was provided a monitor, floor stand, video cables, and a power strip to connect their laptop.

Participants were able to choose their poster presentation format. Some had a one-slide traditional poster, others had PowerPoint presentations, and others still had demonstrations and videos. Three awards were sponsored by Quanta Technologies and judged by workshop participants:

- best student paper: "Cost-Effective Dynamic Control for Transmission Systems," Rohit Jinsiwale, Mickael Mauger, Rajendra Prasad Kandula, and Deepak Divan, Georgia Institute of Technology; Marion Jaroszewski, Delta Star; and Joe Schatz, Georgia Power
- best student paper: "Development of Controller Hardware-in-the-Loop Platform for Microgrid Distributed Control Applications," Yuhua Du, Hao Tu, Srdjan Lukic, and David Lubkeman, North Carolina State University; and Abhishek Dubey and Gabor Karsai, Vanderbilt University
- best e-poster: "Analysis of Coordinated HVDC Control for Power Oscillation Damping," Joakim Björk, Karl Henrik Johansson, Lennart Harnefors, and Robert Eriksson, Kungliga Tekniska Högskolan Royal Institute of Technology.

FIG 6 Members of the IEEE eGrid Steering Committee. (Photo courtesy of Johan H. Enslin.)

Sponsors of IEEE eGrid 2018 included Siemens, Duke Energy, Dominion Energy, ConEdison Battery Storage, RTDS Technologies and Nayak, Opal-RT, Typhoon HIL, South Carolina Electric & Gas, Southern Current, GE Power, the IEEE Standards Association, the Center for Power Electronics Systems, Seeds & Grapes, the Center for Distributed Energy at the Georgia Institute of Technology, the Energy Production & Infrastructure Center at the University of North Carolina at Charlotte, the Future Renewable Electric Energy Delivery and Management System Engineering Research Center at North Carolina State University, the Clemson University Research Institute, Flexible Electrische Netz-RWTH, IEEE Empower a Billion Lives, Quanta Technology, and the IEEE Coastal Section.

We thank the IEEE eGrid 2018 Local Organizing Committee, especially Crista Hartenstein, the IEEE eGrid Steering Committee (Figure 6), session chairs, authors, panelists, reviewers, moderators, note takers, and attendees for their dedicated work to make IEEE eGrid 2018 a success. We also thank the PELS and PES as the workshop technical and financial sponsors. Participants in the workshop included 95 people from industry and 40 students. The full IEEE eGrid 2018 proceedings is published online (https://www.ieee-egrid.org/2018/program/).

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