CURENT Develops Power Electronics For A More-Resilient Electrical Grid

by Leon Tolbert, Center For Ultra-Wide-Area Resilient Electric Energy Transmission Networks (CURENT), Knoxville, Tenn.

The field of power electronics is ripe with opportunities. New technology is being developed at a rapid pace, the industry is expanding, and research projects are in progress that have the ability to change the way the power industry operates today. For power electronics students, this means the chance to participate in very important and exciting avenues of study.

CURENT, the Center for Ultra-Wide-Area Resilient Electric Energy Transmission Networks, is one of five National Science Foundation (NSF) Engineering Research Centers (ERC) focused on energy and infrastructure. It is the result of a collaboration between academia, industry and national laboratories and is jointly supported by NSF and the U.S. Department of Energy (DOE). The center itself is a partnership of four research institutions led by the University of Tennessee in Knoxville, TN (UTK) and includes Northeastern University, Rensselaer Polytechnic Institute, and Tuskegee University.

The CURENT vision is to develop a nationwide or continent-wide transmission grid that is fully monitored and dynamically controlled in real-time for high efficiency, high reliability, low cost, better accommodation of renewable energy sources, full utilization of energy storage, and accommodation of responsive load. CURENT looks to develop technologies that enable ultra-wide-area grid control, high penetration of renewables and better reliability, and there is a need to develop a system for demonstrating and verifying such technologies.

Educating Power Engineers

Across the four partnership universities, there are over 100 students enrolled in the CURENT program, which offers classes in advanced power electronics; power systems reliability, operations, protection and stability; power quality; high-voltage engineering; distribution systems; electric and hybrid vehicles; and renewable power integration, to name a few. UTK has more than 70 graduate students in CURENT, with over 30 of these doing research in power electronics. In terms of power electronics research, CURENT presently has 24 Ph.D. students, three M.S. students, four visiting Ph.D. students, two visiting scholars, three post docs, and five undergraduates.

One of the unique aspects of the education program at CURENT is that many of the power electronics students also take courses in power systems, utility applications of power electronics and alternative energy sources. Drs. Fred Wang and Daniel Costinett have also initiated unique courses where "students teach students," meaning a different student is responsible each week for teaching a particular topic. These courses include significant hands-on training and best practices for various laboratory methods such as double pulse testing of power electronics devices, reliability testing, protection methods in power electronics, PCB design and many other topics. Students are also engaged in designing and constructing a dynamometer test stand.

Throughout CURENT, there are multiple opportunities for both power systems and power electronics students as undergraduates and at the graduate level. Students have the opportunity not only to do research, but also to be involved with other center activities such as industry collaboration; technology and educational seminars; conferences; professional development; mentorship with industry; and participation in domestic and international exchanges with partner universities and industry partners. CURENT seeks to educate and prepare a new generation of electrical engineers and leaders in the fields of power systems and power electronics.

Power Electronics Research

As researchers develop new wide-area controls and situational awareness techniques, these ideas must be evaluated in a real-time environment. Since it is not possible to reconstruct the power grid, researchers at CURENT have developed a hardware testbed (HTB) that uses reconfigurable power electronics to emulate the power grid. The HTB, together with the software-based large-scale testbed (LTB), form the demonstrative CURENT systems.

The goal of the HTB is to construct a real-time scaled power systems emulator that represents the electric grid with sufficient detail; enables easy integration of new measurements, sensors, transmission schemes, communication and control; and provides a platform for demonstrating and testing the CURENT systems and developing technologies in a grid environment.

CURENT plans to represent the North American power grid through an emulation of "eight nodes" connected through "transmission lines." Each node represents a cluster of generation and loads, which captures the electromechanical characteristics of the North American power system. Although the HTB can only represent limited complexity in size, it can naturally accommodate and test various technological complexities (hardware, software, measurements, multi-time scales, nonlinearity) in a single testbed in real time.

The emulator can accurately represent different generation sources (synchronous generator, wind turbine, photovoltaic source), energy storage (flywheel, battery, electrochemical capacitor), and loads. The HTB is also able to emulate different kinds of common power system load types, including static and dynamic loads. Static loads are represented by combinations of constant impedance, constant current and constant power. ZIP load is used to represent the bulk of the load in the power system. Dynamic load is represented by detailed induction machine emulators (power electronic converters) that can accurately represent the startup and dynamic characteristics of machines.

Thus far, a total of three clusters have been built for multi-area power system emulation. A central remote control room (visualization room) was established for monitoring and sending operation commands; and the hardware test-bed provides a platform for emulating power system scenarios and implementing advanced control algorithms. The testbed results are validated by comparison with off-line studies and measurements from the real power system. Future research will focus mainly on expanding the emulator clusters, including multi-terminal HVDC; realizing more emulating functions; developing system-level real-time monitors and controls; and serving as a platform for demonstrating various scenarios with new algorithms and technologies from other thrusts/projects.

Hardware Testbed Projects

There are three grid emulation projects that are currently in progress:

Multi-Terminal AC-DC

Multi-terminal AC-DC investigates the use of voltage source converter (VSC) based multi-terminal high-voltage direct current (HVDC) systems to integrate a high penetration of renewable energy. It focuses on system modeling and design, as well as implementation of control and protection schemes. The multi-terminal HVDC testbed will also be used to study the potential benefits brought by an HVDC system to the ac grid such as voltage and frequency support, oscillation damping, etc. Currently, a 4-terminal HVDC system made of two 2-terminal HVDCs has been built and several operational scenarios, e.g., startup, active and reactive power step, converter failure and line open have been tested.

Integration Of High Penetration Of Renewables

Emulators in the HTB can provide flexible and accurate modelling of various types of renewable energy sources and energy storage. Renewable energy needs to be studied not only from the standpoint of generating electricity, but also from the standpoint of how this energy effects the grid. "Green" and other nontraditional power and storage sources are often unreliable or inconsistent and often need to be stored and converted. Energy storage includes battery, electrochemical capacitor (ultracaps), flywheels, etc. Here energy is stored in the form of chemical/kinetic energy and a power electronics converter helps to convert the electrical energy back and forth. This project is intended to develop generation- and transmission-level technologies through emulation and explores alternative energies such as wind and solar. Research is ongoing.

Voltage Collapse

The voltage collapse project demonstrates a real-time measurement-based voltage stability monitoring and control strategy. A two-area HTB system was constructed to validate the effectiveness of real-time voltage stability monitoring and closed-loop control and as comparison to traditional methods of voltage stability techniques. In today's power system, operators have very limited information about voltage stability, which leads to a conservative operation of the power system. With more situational awareness, operators can now push the system further and still maintain high reliability. After successful experiments on the two-area HTB system, the HTB system is being expanded to a multi-area system to study more advanced detection algorithms and complex power flows in the system.

CURENT Power Electronics Faculty

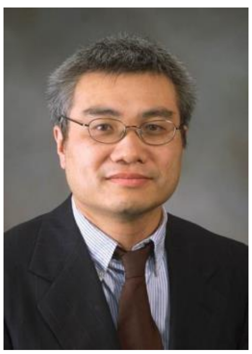
The power electronics faculty in CURENT consists of research leaders who have made many contributions to their field. In my role as the Min H. Kao Professor and UTK Department Head for Electrical Engineering and Computer Science, I lead the power electronics curriculum and research and as the Thrust Leader at CURENT, I run the hardware testbed project.

Dr. Leon Tolbert

Leading the HTB project is one of my strongest interests. We are changing the way the grid is viewed and operated, and that in itself is exciting. The work we're doing here in power electronics will change the architecture and control of power systems and their embedded power electronics and influence the smart grids of the future.

I also hold a part-time appointment at Oak Ridge National Laboratory, serve as an editor for the IEEE Transactions on Industry Applications, and have held several leadership roles in the IEEE Power Electronics Society. I'm also a registered Professional Engineer in the state of Tennessee and an IEEE Fellow.

My areas of research interest include high-efficiency electric power conversion for data centers, application of wide-bandgap (SiC and GaN) power devices, multilevel converters, electric vehicles, renewable energy interfaces, and utility application of power electronics.



Dr. Fred Wang

Dr. Fred Wang, Condra Chair of Excellence in Power Electronics, is the technical director of CURENT and is the leader of the power electronics actuation thrust of CURENT. Wang is a professor in electrical engineering at UTK and holds a joint appointment with Oak Ridge National Laboratory.

Wang is also a Fellow of the IEEE, associate editor for the IEEE Transactions on Power Electronics, and brings his several years of industrial experience at General Electric to the classroom and laboratory research. His research areas include aerospace power electronics; electric vehicle applications; packaging and use of wide-bandgap power electronics such as SiC and GaN; and utility applications such as renewable energy interface, microgrids, and HVDC.

Dr. Daniel Costinett

Dr. Daniel Costinett is the education co-director for CURENT, and has a research focus on dc-dc converters. Costinett is an assistant professor in the Department of Electrical Engineering and Computer Science at UTK. He is presently leading UTK's efforts for the Google Little Box challenge to develop a small, efficient power supply.

Costinett also leads electrical engineering and computer engineering students participating in DOE's EcoCar3 Challenge in the development of an electric vehicle. His research areas include resonant and soft-switching power converter design, energy harvesting, high-efficiency converters for data center power supplies, implantable devices, and electric vehicles.

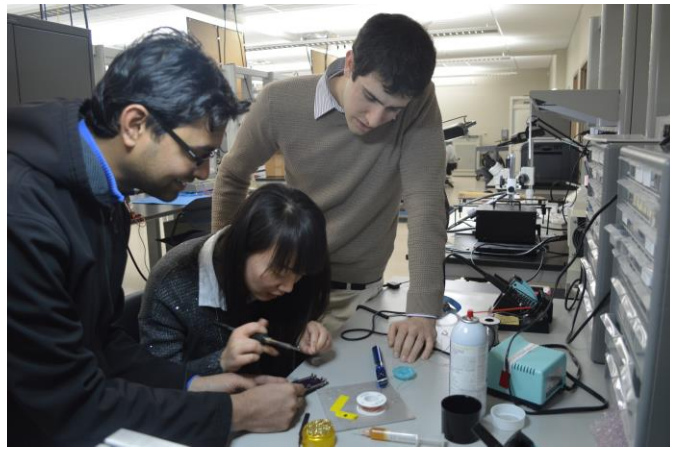
CURENT Facilities

CURENT has a wide array of top notch facilities and labs. The following three, in particular, are pertinent to the power electronics research and program.

Power Electronics Laboratories

Consisting of a low-power advanced semiconductor devices application laboratory and high-power energy and motor laboratory, the University of Tennessee-Knoxville power electronics laboratories take up more than 4000 sq-ft of space in the new $37.5 million Min Kao Electrical Engineering and Computer Science Building. Funded since 2010 by more than $1.5M for equipment purchases, the power electronics labs are devoted to establish a high-quality and diversified power and energy research facility.

These labs have been fulfilling the role of actuation and implementation platform for CURENT. Existing state-of-art research projects in the lab include SiC and GaN semiconductor device applications for ultra-high-efficiency data center power supplies and high-power-density motor drives, aerospace power electronics applications, higher reliability and fault protection schemes for multilevel converters for use in HVDC transmission systems, and stability study for high penetration of wind and solar renewable energies in the grid.



Dr. Wang with Edward Jones (left image) and Dr. Costinett with Saeed Anwar and Ling Jiang (right image) in the Power Electronics Lab.

Hardware Testbed Lab

The hardware testbed lab contains a series of cabinets with power electronics that are used to emulate the grid and its activities. In this room, a power electronic converter based Hardware Universal Grid Emulator (HUGE) allows testing of different power system architectures as well as integration and demonstration of key technologies on monitoring, control, actuation and visualization.

Dr. Tolbert and Jessica Boles in Hardware Testbed Lab.

The future grid system will integrate advanced technologies like HVDC, HVAC, renewable energy resources, responsive loads, and energy storage systems, etc. Before implementing them, they need to be evaluated for their impact on the grid as accurately as possible. The Hardware Universal Grid Emulator (HUGE) will be an invaluable tool in verifying the predicted performance and interoperability of these technologies.

Liu Yang and Wenchao Cao in the Hardware Testbed Lab.

The hardware testbed is also used to develop power electronics interfaces and controls needed for power system components emulation. These include system models for power system components, such as three-phase steam turbine generators, industrial induction motors, renewable energy generation, aggregated power system load models, transmission lines and energy storage; control interface hardware; and power converters. In addition, the hardware testbed aids in analyzing power system level protection and testing new data architecture and technologies.

The Visualization Room

The visualization room contains a wall of video screens and computers that can stream the data from the hardware testbed, the large scale testbed and the FNET/GridEye. This allows researchers to view real-time and historical data in a large visual environment.

The primary focus of the visualization room is to help with dynamic modeling. The models can include different scenarios of generation mix and operating scenarios, wide-area measurements, new actuation technologies and new control strategies.

Liu Yang, Dr. Tolbert, Mitch Smith, and Yiwei Ma in the Visualization Room.

Industry Partners

CURENT presently has 25 companies and organizations that are partners or members of the center. Member organizations include EPRI and NRECA; U.S. National Laboratories ORNL and NREL; several utilities and ISOs such as TVA, PJM, Dominion, Southern Company, NYISO, NY Power Authority, ISO New England; manufacturers such as GE, ABB, Hitachi, Alstom, Tektronix, National Instruments, Vacon, Global Power Electronics; and software and service companies such as Grid Protection Alliance, Scout, Mehta Tech, and Certes Networks.

Industry partners gain access to the Center's state-of-the-art facilities and software models, personnel and research results. They also form the Industry Advisory Board that helps to determine research directions, offers advice on strategic planning, and provides IP protection in the center. Additionally, through their membership funding, they leverage resources that aid the Center's cutting-edge research and development.

Conclusion

CURENT is training the future workforce who will be leaders in the power electronics and power systems industry and government sector. The power electronics faculty and students in CURENT at the University of Tennessee are working on a wide array of industry and government projects that are making important advances for transportation, power supplies and electrical power system utilities.

Their research spans the gate drive and application of GaN and SiC devices; packaging and EMI issues; high-efficiency dc-dc converters, rectifiers, and inverters; motor drives; and renewable energy interfaces and multilevel converters for high-voltage applications. CURENT works closely with industry to solve today's issues with power electronics and to target future application needs.

For more information on CURENT, see the program website or email the author.

About The Author

Leon Tolbert is a Thrust Leader in CURENT and the Min H. Kao Professor and Head in UT's Department of Electrical Engineering & Computer Science. Tolbert is also an adjunct participant at the Oak Ridge National Laboratory and conducts joint research at the National Transportation Research Center (NTRC). In addition, he is a participating faculty member of the Graduate Automotive Technology Education (GATE) Center at UT, a registered Professional Engineer in the state of Tennessee, and an IEEE Fellow. Tolbert received his B.S. in electrical engineering with highest honors in 1989, followed by his M.S. and Ph.D. in electrical engineering in 1991 and 1999, all from the Georgia Institute of Technology, Atlanta.