CURENT

CENTER FOR ULTRA-WIDE-AREA
RESILIENT ELECTRIC ENERGY
TRANSMISSION NETWORKS

Education Research Industry

Summer **2018**, Issue **7**

Welcome to CURENT

Summer 2018

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Dr. Fran Li

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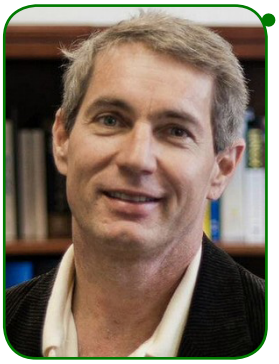

Dr. Kevin Tomsovic

A note from the Director..

Dear CURENT colleagues and supporters,

As we move through our 7th year of operation, we can look back over many accomplishments of the last several years. We have seen an increase in students, both domestic and international, and we now have approximately 175 undergraduate and graduate students in the CURENT program. We also have 22 research associates and research staff and, at any time, 15 to 25 visiting scholars. Several of our research projects have matured and we have filed 18 patents and disclosed 35 inventions. We also have one licensing option in place. Our industry membership program is strong and continues to grow. We now boast 36 industry members, with several more businesses/corporations currently in the negotiation process.

Our 6th Annual Industry Day and NSF / DOE Site Visit was held November 14th-16th, 2017. You will find an article about this event on page nine.

This issue of our newsletter contains research updates for Hardware Testbed (led by Dr. Leon Tolbert and Dr. Fred Wang) and the Largescale Testbeds (led by Dr. Fran Li and myself). These testbeds are central to supporting the research at CURENT and also have great potential for technology transfer and commercialization.

Also, in this newsletter, we introduce you to four newer staff members, all of of whom have joined us since last summer. You will find the introductions under Center News on the back of this page.

We are proud of the development of the Center and now look to move on to our next stage of maturity with a long term plan of sustainable operations. I, and everyone at CURENT, thank you for your continuing interest and support as we begin this phase. Please let us know what is of interest to you, how we are doing and what we can do to support your needs. Your feedback and comments are always welcome.

Sincerely,

Kevin Tomsovic

Partner Schools

TENNESSEE

TUSKEGEE

Rensselaer

Northeastern

Center News

Meet the New Staff Members

Jay Cooley
Administrative Director

Jay is the Administrative Director of CURENT and is responsible for oversight of all financial, human resources and sponsored project operations of CURENT.

Jay joined CURENT in October 2017 and has worked for the University of Tennessee since 2011. He previously worked at the Howard H. Baker Jr. Center for Public Policy in the capacity of Business Manager. In this role he provided financial oversight of the Center since 2014. He started his career in the Sponsored Projects Accounting Department as an Accountant in 2011. In this role he provided support and guidance on sponsored projects for various organizations across the Knoxville Campus. Prior to his employment at the University, he was an auditor for a local CPA firm.

Jay holds a B.S. degree in Accounting from the University of Akron and a B.A. in Finance from the University of Memphis.

Laura Yoder
Financial Specialist

Laura's role of Financial Specialist is to assist in the fiscal and human resource operations as well as substitute authority for the Administrative Director of CURENT.

Laura joined CURENT in October 2017. Her previous experience included Business Analyst with Knoxville Utilities Board and Finance Analyst with Medic Regional Blood Center. Prior to that she worked in Governmental Accounting as Business Manager at the Kankakee Valley Park District in Illinois where she worked in cooperation with the local community college and the community to design and build an Ice Arena and Aquatic Center. She began her career as Finance Director at Moore Industries in Bradley, IL. opening up Industries Sales Distributorships throughout the U.S.

Laura holds a B.A. degree in Business Administration-Management Information Systems from Governors State University, IL.

Anne Skutnik, Ph.D.
Education Coordinator

Anne coordinates CURENT's education and diversity initiatives. This includes pre-college outreach events like Family Engineering Nights, summer programs like the Research Experience for Teachers (RET) and Young Scholars Program (YSP), and university programs like the undergraduate summer research program (REU). She has over a decade of experience in education, starting as a K-12 educator, then as an university instructor and, most recently, as a technology trainer and instructional designer at UT.

She received her Ph.D. in Learning Environments and Educational Studies from the University of Tennessee. Her research focuses on engineering education pedagogy and epistemology. She holds a B.A. in History and in English from Iowa State University, a M.A. in History from Virginia Tech and a M.S. in Instructional Technology from the University of Tennessee.

Ryan Smiley
IT Manager

Ryan is the IT Manager for CURENT. Born and raised in New England, Ryan received an associate's degree in Computer Networking. While earning his degree, Ryan worked as a Desktop Support Specialist for a major hospital network. Having lived in Tennessee for little over a year, Ryan also plans to attend the University of Tennessee in the fall to pursue a bachelor's degree in Computer Science.

Ryan joined CURENT in August 2017.

Large-scale Test Bed (LTB) for Innovations in Wide-Area Power System Technologies

By Dr. Kevin Tomsovic and Dr. Fran Li

Overview

The objective of this project is to develop a software platform for the large-scale test bed (LTB) thrust that can serve as a real-time grid operation platform to continuously simulate the operation of an actual power grid with small or large disturbances using communication and control actions as considered under wide-area measurement. While the traditional power system simulators only focus on the physical power system components, the LTB incorporates power system components, communication networks, energy management systems (EMS) and a measurement-based control system into an integrated platform for researchers to address emerging challenges such as renewable energy integration and cyber-physical security under innovative measurement-based technologies and controls.

LTB is designed to run large-scale power grid models up to thousands of buses with modern power system components such as voltage source converter, multi-terminal high-voltage dc network, and wind turbines. Interfaces to different simulation engines are available to gain capabilities including real-time simulation, high-performance computing, and fast model prototyping. Scenarios including high penetration of wind power, generation mix, and seasonal load balances are created in the North American large-scale systems. As a software platform, the testbed is flexible to quickly plug in novel power system infrastructures and wide-area measurement-based control methods for studies under high penetration of renewable energy.

Technology Pathway

The LTB platform is designed on a decoupled architecture based on the concept of modules. With the data interfaces properly defined, each module runs its own routines independently and communicate with other modules through data streaming. The modules are categorized into four types based on functions: grid simulators, measurement devices, energy management system, and control methods. These modules, the underlying communication network, and the large-scale system models make up the LTB for wide-area measurement-based control technologies.

The core algorithms of modules are developed by the research thrusts in CURENT. A data streaming client is attached as a bridge between the core algorithm and the external modules. By connecting the streaming clients to the data server, the modules can send data to the destination modules, or receive data from others. Data packets go through the underlying communication network, which can be further studied with a communication network emulator. The decoupled architecture of LTB is illustrated in Figure 1.

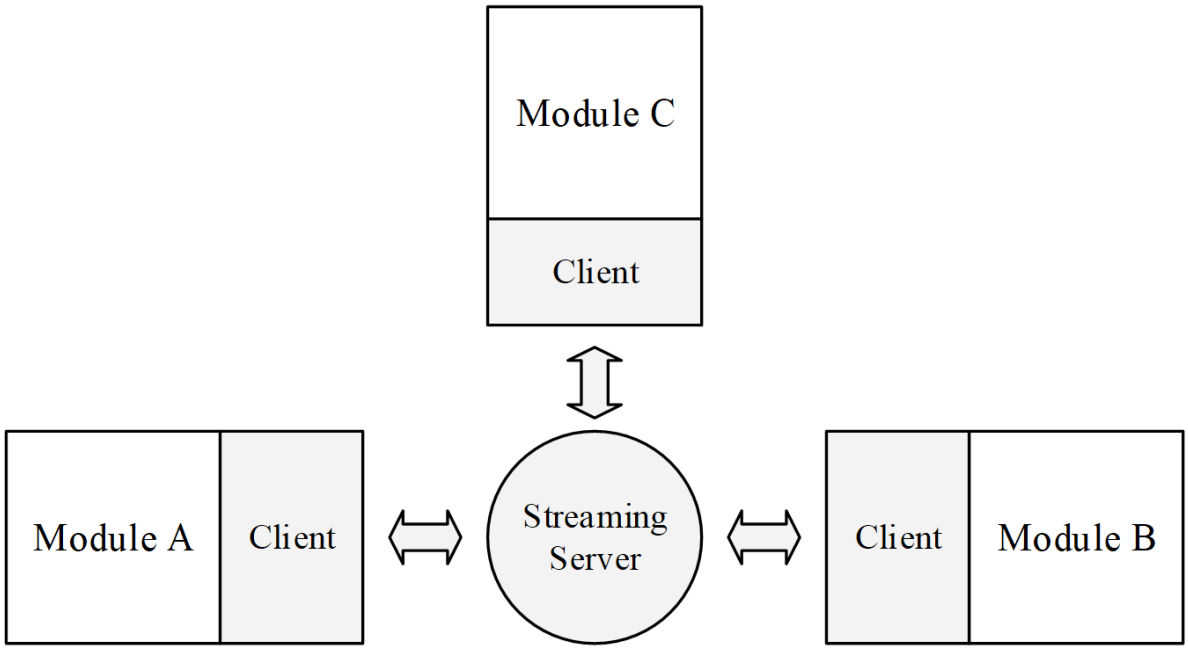

Figure 1: Data streaming-based decoupled architecture

Large-scale Test Bed (LTB) for Innovations in Wide-Area Power System Technologies (cont.)

The LTB strives to mimic the structure and operation of a real power system. Figure 2 shows the overall architecture and the structural organization in LTB, which consists of four categories of modules: system models and scenarios, power grid simulator, an energy management system, and a measurement-based control system. CURENT North America system scenarios with a high penetration of renewables are created for different seasons. The grid simulator produces algebraic and state variable data from time-domain integration on a large-scale grid model. The measurement system receives the raw state, imposes measurement errors and delays, and send the measurements to the state estimator. The state estimator sends the estimated states to control modules for further processing. Control signals from the control modules are sent back to the grid simulator for actuation.

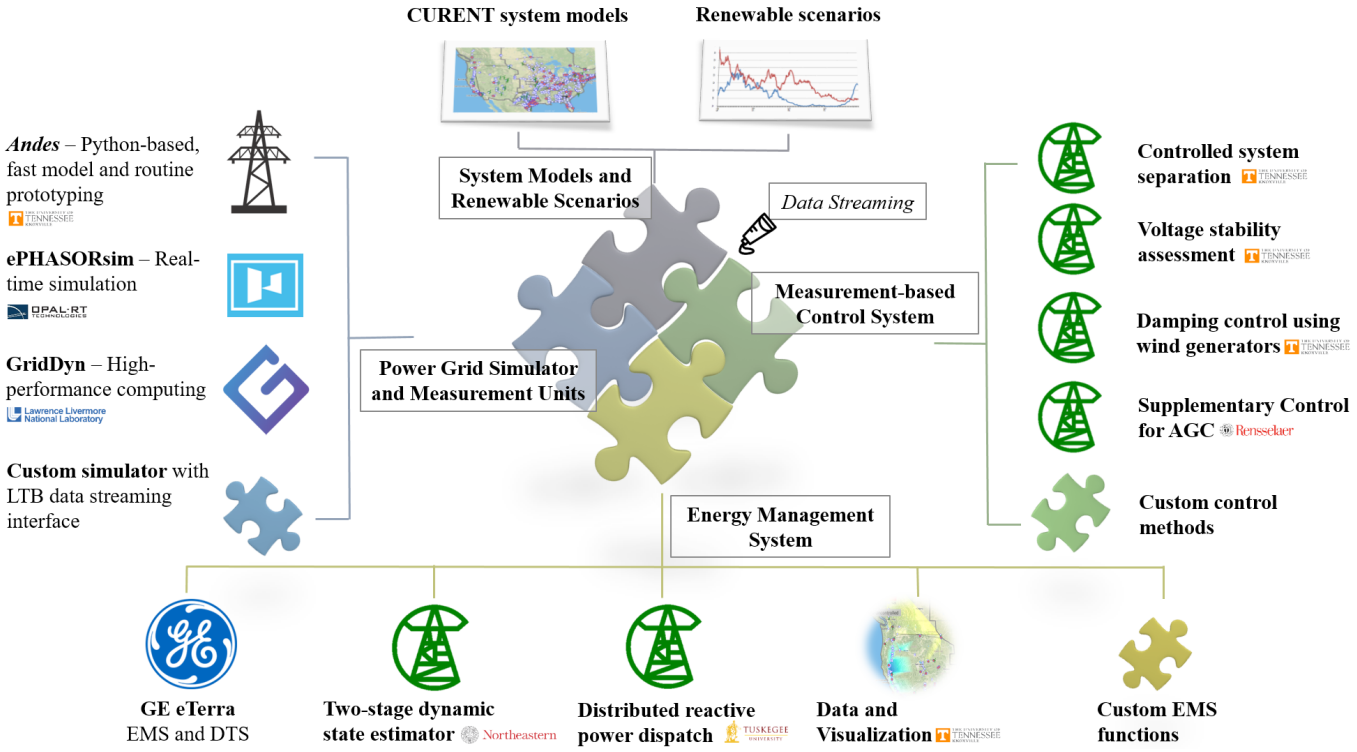

Figure 2: Overview of the Large-Scale Testbed architecture and components

The extended-term dynamic power grid simulator is a differential algebraic equation (DAE) solver plus the component models defining those equations. LTB has interfaced three dynamic simulators for different purposes: a) Andes, a Python-based, in-house developed simulator, for fast model prototyping; b) OPAL-RT ePHASORsim, a commercial simulator with real-time simulation capability; and c) GridDyn, a high-performance grid simulator developed at Lawrence Livermore National Laboratory. Using these simulators, LTB maintains flexibility in research modeling and large-scale real-time applications.

The measurement system in the LTB platform is modeled as a component linked to the simulator, taking accurate values and adding errors and delays. Probabilistic models are used to describe the measurement noises and errors where the probability distribution is fitted with the actual measurement device. Measurement data is taken at the measurement frequency, typically 30 Hz, and then time stamped before sending to the receivers such as the state estimation module.

Energy management functions in the LTB performs routines for security screenings and optimizes the economic aspects of system operations. For example, the game theory based reactive power control program calculates the optimal voltage set point to maximize the system robustness. Another example is the N-1 contingency screening that performs mass parallel power flow analysis for N-1 contingencies. All the states and calculated data are sent to the EMS visualization module, which is the user interface for researchers. The live or recorded simulations are visualized in the web browser using an in-house interactive visualization platform as shown in Figure 3.

Large-scale Test Bed (LTB) for Innovations in Wide-Area Power System Technologies (cont.)

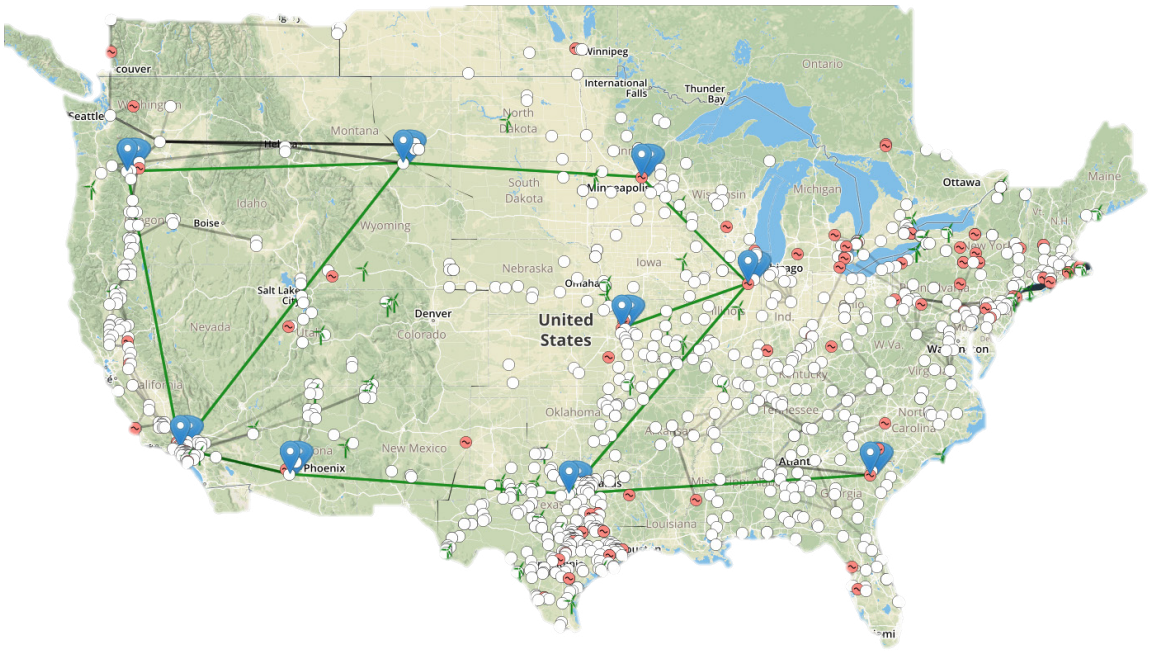

Figure 3: Visualization of the 1,000-bus CURENT system with 50% wind and a nine-terminal HVDC

The control system consists of the wide-area measurement-based control methods developed in the CURENT thrusts. Over the years of development, several control methods have been implemented on the LTB, including controlled system separation for the WECC system, voltage stability assessment, damping control, and frequency control. The control methods were developed in standalone mode with the simulation data dumped from the simulators. When the methods are mature, they are interfaced to the LTB platform via data streaming, which provides the inputs to the control methods.

Impacts

The LTB provides a testing platform to validate and verify new models and control technologies developed in CURENT. It also serves as a driver of research since it allows fast prototyping of new models and grid infrastructures, direct access to simulation and measurement data, and instant feedback of the wide-area control signals. Thus, it is of critical importance to the success of the CURENT research visions.

Above: Working in the Visualization Room, MHK 124

Year 7 - Pre-College Program

University of Tennessee Outreach

CURENT hosted Family Engineering Nights at the following schools: Green Magnet STEAM Academy, Clinton Elementary, Sequoyah Elementary, Lake City Elementary, Spring Hill Elementary, Grand Oaks Elementary, and Whittle Spring Middle School.

This year was CURENT's first time at Clinton Elementary, and nearly 400 parents, teachers, and students came out to learn about engineering. Solar car races and a dance pad made by CURENT students were popular stations, but stations that focused on teamwork and problem-solving were also popular with students and teachers. One parent told us that, "I have 3 boys that go to CES, and they ALL had a blast tonight!"

It was CURENT's sixth year partnering with Sequoyah Elementary for Family Engineering Night. In addition to CURENT, UTK's Department of Geography brought an Augmented Reality sandbox, and Knox County Schools came with their Virtual Reality headsets. Over 400 people attended the Sequoyah event, and many parents shared positive feedback, including "My son said this was the best family engineering night ever, and he's a fifth grader so that's a great sign since some events tend to get stale over time."

Over 1550 parents, teachers, and students attended the seven Family Engineering Nights for Year 7.

Above: Family Engineering Night – Clinton Elementary

Above: Family Engineering Night – Sequoyah Elementary

Above and right: Family Engineering Night – Sequoyah Elementary

CURENT also produced an e-book for elementary school teachers focusing on electrical engineering. Lessons in the book were created by RET participants. Some lesson topics include introduction to the power grid, circuit basics, energy poverty, and renewable energy.

Additionally, CURENT has hosted lab tours for three diversity oriented groups this year. In February, CURENT collaborated with the Tickle College Office of Diversity Programs to host a lab tour for students newly admitted to the college. Over 36 parents and 18 students attended. In April, CURENT hosted a lab tour for 10 students as part of the Systers - Little Systers event. And in June, CURENT hosted 23 high school students, teachers, and college students for a lab tour in conjunction with Office of Diversity Programs and Possibilities in Secondary Education and Science (PiPES) a STEM outreach program.

Rensselaer Polytechnic Institute Outreach

The Rensselaer Polytechnic Institute (RPI) Engineering Ambassador program http://engineeringambassadors.union.rpi.edu/ supports the RPI School of Engineering community educational outreach in classrooms as well as special community community events. This Fall 2017, the undergraduate RPI Engineering Ambassadors supported 11 events on a full range of engineering topics. Three school visits included a CURENT ERC (http://curent.utk.edu) related talk and hands-on activity on Thermoelectric Devices and one school visit included a talk and hands-on activity on Wind Energy. It is estimated that 300 middle school students participated in these particular CURENT ERC related activities at the school events.

The RPI Engineering Ambassador also presented the Wind Energy topic at a Rise High http://rise-high.org/ recruitment event for a new multi-year program to begin in the spring semester for students within a seriously challenged community. The RPI Engineering Ambassador will be supporting the Rise High Saturday morning program in the spring semester beginning with the topics of Energy: mechanical, thermal and electrical energy.

Above:: RPI Rise High Recruitment Night on October 19, 2017

Summer REUs (Research Experience for Undergraduates)

Northeastern University (NEU) - Two REU students are working at NEU this summer. They are developing a graphical user interface which allows the user to customize the input files for power flow analysis and state estimation. They are also compiling a new version of Power Education Toolbox to make optimal power flow problems functional and to make the program available for mixed AC/DC system topologies.

Rensselaer Polytechnic Institute (RPI) - The REU students at RPI have been introduced to data analytic techniques, such as multiple linear regression and statistical neural networks. These techniques are being applied to real-world data sets provided by power system utilities and further applied to the data harvested from a prototype solar power data acquisition system that the students will assemble themselves.

University of Tennessee, Knoxville (UTK) - Seventeen undergraduates and recent graduates are conducting summer research at UTK. Of these seventeen, eleven are visiting students from other US schools including: Smith College; University of Denver; Jackson State University; University of Hawaii at Manoa; Grove City College; Seattle University; University of Kentucky; Western Kentucky University; University of Puerto Rico Mayaguez; University of Idaho; and Mississippi State University. These students are studying a range of topics like social-psychological studies of electrical vehicle adoption, the impact of wind and solar power penetration on the grid, optimal PMU placement as it relates to line failures, and GaN-based Boost Converter Design.

Industry Highlights

Site Visit 2017

CURENT's 6th Annual Industry Day and NSF / DOE Site Visit was held November 14th-16th, 2017. This was a particularly important event as this was a funding renewal year that will extend funding through August 2021. We hosted 49 industry and innovation partner representatives and 11 University of Tennessee administrators led by UTK Provost John Zomchick. In attendance as well were partner school Deans, pre-college education partners, faculty and SAB members and graduate and undergraduate students. In total, CURENT hosted nearly 300 people at this year's meeting. Our speaker lineup was exceptional and included:

- Terry Bilke, consulting advisor at Midcontinent ISO (MISO) - *Situational Awareness Signals in Grid Frequency*;
- Sterling Rooke, Director-Elect ISA Communications Division at Brixon - *Total Industrial Awareness: is it physical or cyber*?;
- Capt. Lynn J. Petersen USN (ret.) from the Office of Naval Research - *Navy Application of Silicon Carbide (SiC) Wide Bandgap (WBG) Semiconductors Enabling Future Power and Energy Systems*;
- Joseph Yan, Principal Manager of Price Forecasting & Modeling with Southern California Edison - *California Environmental Initiatives and Electricity Industry Transformation*;
- Allen Hefner, DOE Technology Manager from DOE/NIST - *Power Electronics for Resilient Distributed Generation Grids*;
- Venkat Banunarayanan, Associate Director of Distributed Generation, Business & Technology Strategies at NRECA – *Applied Research Projects and Programs at NRECA*; and
- Marianna Vaiman, Executive Vice-President of V&R Energy - *Advanced Software Tools for Enhancing Power System Reliability and Resiliency*.

Twenty eight students presented technical papers in sessions chaired by faculty members. The papers were grouped as follows: Power System Modeling and Estimation, Power Electronics and Renewable Energy, Power System Control and Power Monitoring and Operations. Faculty gave overviews of the five CURENT Thrusts – Monitoring, Modeling, Control, Actuation and Engineered Systems as well as presentations about the Innovation and Industry Collaboration Program, CURENT Infrastructure, CURENT's Diversity and Culture of Inclusivity, and University and Pre-college Education Programs. All of the CURENT faculty participated in these overviews.

This year's event also included a series of meetings and presentations regarding the Center's Sustainability Plan. The site visit is always an exciting time for us and it gives us a chance to highlight our research, students and the innovative work that goes on at the Center and also gives our students an opportunity to hear about new breakthroughs and to discuss issues in the industry. energy efficiency related issues.

Above: Students field questions in the visualization room after the large scale testbed demo.

Right: Dr. Leon Tolbert addresses the crowd on Day 1 of the Site Visit.

New Industry Members

We'd like to welcome CURENT's newest Industry Members. They are American Transmission Company (ATC), Waukesha, WI; Brixon, Inc., Baltimore, MD; Global Technical Systems (GTS)/SPARQ, Virginia Beach, VA; and Knoxville Utilities Board (KUB), Knoxville, TN. We are proud to announce that our Industry Membership now stands at 36.

CURENT would like to thank all our Industry Partners, the NSF (National Science Foundation) and the DOE (Department of Energy)

Upcoming Events

Join us:

August 5-6, 2018
IEEE PES General Meeting
Portland, OR

August 9 – 10
CURENT Strategic Planning Meeting
Portland, OR

CURENT
CENTER FOR ULTRA-WIDE-AREA RESILIENT ELECTRIC ENERGY TRANSMISSION NETWORKS

contact us

Min H. Kao Building, Suite 555
1520 Middle Drive
Knoxville, TN 37996

865.974.9720 (ph.)
865.974.9723 (fax)
info@curent.utk.edu