ERC for Ultra-wide Area Resilient Electric Energy Transmission Networks (CURENT)

University of Tennessee–Knoxville (lead institution)

Designing the nation's future electric power transmission system for greater efficiency, higher reliability, lower cost, and better accommodation of renewable sources

A National Science Foundation Engineering Research Center since 2011

Partner Institutions:

- ***Northeastern University***
- ***Rensselaer Polytechnic Institute***
- ***Tuskegee University***

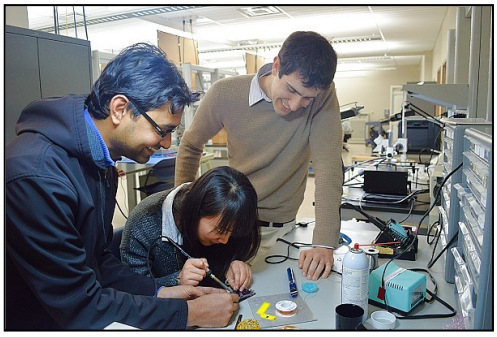
Perhaps the most important technical challenge facing the electric utility industry over the next several decades is how to address societal energy needs without heavy reliance on fossil fuels. Less appreciated in this discussion is the critical role that the electric power system transmission infrastructure must play in any viable solution. With most of the renewable resources in the US being located far from population centers or having characteristics that make operation on a local basis difficult, having a transmission system that can accommodate a large penetration of renewables and other changes in generation mix is necessary for the grid of the future.

Fundamental breakthroughs are needed to control interconnection-wide dynamics and manage resources across vast geographical distances, widely varying timescales, and diverse production sizes. This is the challenge addressed by the Engineering Research Center (ERC) for Ultra-wide Area Resilient Electric Energy Transmission Networks (CURENT). CURENT's vision is to have a nation-wide or continent-wide transmission grid that is fully monitored and controlled in real-time and that supports a system with high levels of renewable penetration while maintaining the same level of reliability we have today in the grid.

The research challenges for this future power grid primarily stem from variability in generation and coordination across vast distances. A high penetration of renewable sources poses unique considerations including that they: (1) are not as fully dispatchable as fossil fuel generators; (2) suffer from unusual operating characteristics, such as unpredictable rapid variation or slow response times; (3) have seasonal and daily fluctuations that do not generally match daily and seasonal cycles of load variation, which prevents regular and consistent flows across the system; (4) tend to be far from load centers, requiring transfers over long distances; and (5) are generally smaller in size and numerous, so that system operations must coordinate potentially millions of control points. The challenge of coordinated controls stems from the fact that distant events can have system-wide effects with complex dynamics; but system response is poorly understood and constantly changing, while system-wide communication is inherently limited.

Research

CURENT research is a systems-level approach to addressing the challenges of integrating renewables into the extremely large and complex power grid. This problem requires a multi-disciplinary Center approach in order to: (1) have a sufficiently large and diverse team of researchers to address the various research challenges; (2) interact closely with industry to understand practical systems issues; and (3) create the innovation culture needed to transform the large legacy system.



Power electronics lab

The Center identifies the following specific goals as performance indicators for the CURENT system:

- reduce the rate of major power blackouts by 80%;
- increase transmission capacity utilization by 30%;
- allow renewable resource penetration of 50% or greater, without impacting reliability;
- realize wide-area control of responsive loads; and
- achieve near nation-wide grid situational awareness at all control centers.

To realize these goals, we laid out several research milestones for the first five years, including establishing:

- a high-fidelity model of the CURENT system represented by the testbeds with a variety of future operating scenarios;
- new high-resolution measurement technologies for synchronized measurements and for other sensing technologies;
- a control and information structure that is less hierarchical and allows a decoupling of control design to facilitate renewable integration and demand response;
- a systems methodology to take advantage of advancements in wide-area measurement and communication for coordinated action on a continental ultra-wide scale;
- use of high-performance computing to realize large-scale and faster-than-realtime simulation for predictive control coupled with new visualization tools;
- new transmission system architectures that can more fully utilize system capacity;
- effective strategies for the use of utility-scale storage;
- approaches to mitigate cybersecurity threats to grid operation;
- counter-response measures to prevent cascading outages using wide-area measurements; and
- market structures and incentives to ensure optimal pricing, adequate investment in the transmission network, more rapid adoption of renewable technologies, and a fair sharing of social benefits of the transformed infrastructure.

The CURENT research program is organized around four key areas essential to the CURENT vision of wide-area coordinated control of the transmission grid. These four areas, together with the System Testbeds, constitute the five research thrusts for the CURENT research program.

Monitoring Thrust develops the fundamental knowledge and enabling technologies for wide-area system information collection, processing and interpretation, and situational awareness. In the Fundamental Knowledge plane, this thrust covers Wide-area Measurements techniques; in the Enabling Technologies plane, it covers Situational Awareness and Visualization.

Modeling and Estimation Thrust develops the system and component models and modeling methodology for analysis, situational awareness, and wide-area control. In the Fundamental Knowledge plane, this thrust covers the Modeling Methodology; in the Enabling Technologies plane, it covers Estimation, Communication, and Cybersecurity.

Control Thrust develops system theory and architecture for wide-area coordinated control, and also studies the technologies essential for the control implementation. In the Fundamental Knowledge plane, this thrust covers Control Architecture and Economics and Social Impact; in the Enabling Technologies plane, it covers Control Design and Implementation.

Actuation Thrust studies grid architecture and develops actuation technologies suitable for high penetration of renewables and wide-area control. In the Fundamental Knowledge plane, this thrust covers Actuator and Transmission Architecture Technologies; in the Enabling Technologies plane, it covers System-level Actuation Functions.

System Testbeds Thrust is CURENT's Engineered Systems thrust. Two testbeds have been developed: (1) Large-scale System Testbed (LTB), and (2) Hardware Testbed (HTB). The functions of these testbeds are two-fold: to demonstrate and test technologies developed in the Fundamental Knowledge and Enabling Technologies thrusts; and to drive the research in the other thrusts through system-level requirements and specifications.

Education

The education program supports the Center's strategic plan by cultivating students' creativity and innovation. Programs are designed to enhance students' adaptability and to enable them to thrive in a global environment. The CURENT education team has established the following objectives to enhance students' academic experience. These are:

- to establish programs that increase the participation of U.S.-born women and underrepresented minority students;
- to design a multi-disciplinary curriculum focused on electrical energy transmission system analysis and problem-solving skills;
- to develop connectivity with industry, partner institutions, and the larger power and energy system community; and
- to introduce pre-college and undergraduate students to the possibility of pursuing careers in engineering.

Students are offered new courses, certificates, and academic concentrations. Undergraduate students have access to a new academic minor in Electrical Power and Energy Systems, which creates the opportunity to develop technological depth in areas other than their major degree. The education team has constructed a retention hypothesis to increase the completion of undergraduate baccalaureate degrees in electrical engineering. Through research programs, mentoring networks, industry connectivity, and professional development, the Center seeks to increase levels of undergraduate retention. At the graduate level, the Center created a certificate program that is offered to all CURENT graduate students. The graduate certificate provides additional depth into the discipline and increase students' marketability post-graduation. In addition, the core "CURENT" courses are led by key faculty at all partner institutions, which exposes students to diverse teaching methods and styles.

Large-scale testbed

Research experiences are offered to undergraduates (REU), high school students (Young Scholars Program, or YSP), and teachers (RET). These programs provide a rich opportunity for students and teachers to perform research and expand their knowledge of electrical engineering and the engineering design process. Goals of these research experiences include improving

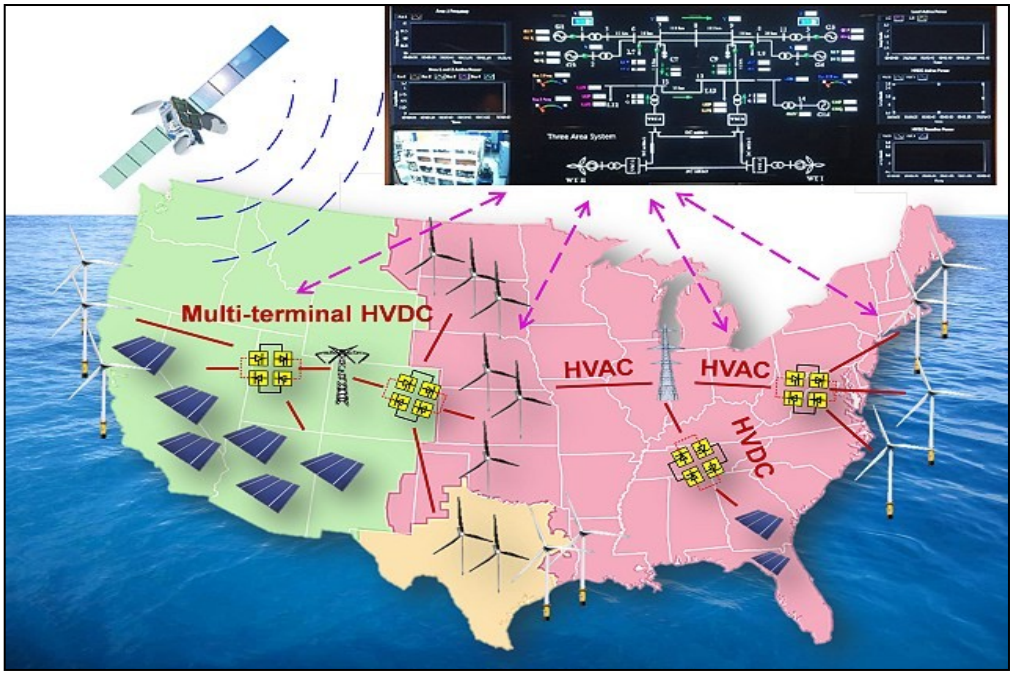
technical knowledge, infusing the K-12 classroom with engineering curricula, and inspiring students to pursue engineering in their future academic endeavors.

In an effort to encourage creativity within the engineering graduate student population, we have designed the IMPACT program. Key components of the program include identifying accomplishments in areas of problem solving and analytical skills, communication, leadership, mentoring, and interdisciplinary skills with a global connection. Through the combined academic and professional development efforts—along with the powerful partnerships created with faculty, alumni and industry—students will enter the next phase in their engineering careers fully equipped to meet the challenges of the 21st century.

CURENT's education program also contains a K-12 outreach component. The strategic plan for the Center's K-12 program is based on an early-intervention theory, which is that if students are engaged in STEM fields from an earlier age, they will be more likely to pursue these areas in college and for careers. Students, staff, and faculty from the Center have participated in Science Nights (which are aimed at engaging parents and young students) and have taught electrical engineering classes at area schools. Throughout each semester, CURENT also invites partner schools to campus for lab tours, hands-on demonstrations, and a variety of additional educational opportunities.

Innovation Ecosystem

The CURENT Industry and Innovation program's goal is to create a culture that links engineering research to technological innovation through sustained partnerships with industry/practitioner organizations to stimulate transfer of ERC research and technology into commercially viable products. These technology transfer activities also offer unique opportunities to form start-up companies by leveraging industry and ERC expertise. With a strong partnership with Oak Ridge National Laboratories (ORNL), the University of Tennessee–Knoxville (UTK) has been a leader in energy-related research and innovations. Partner schools Rensselaer Polytechnic Institute (RPI) and Northeastern University (NEU) both are highly regarded research universities with strong industry support, enhanced by their involvements in other past and current ERCs. Additionally, partner school Tuskegee University is consistently ranked as one of the nation's top producers of minority graduates in engineering and science fields. The ERC team members all have had direct collaboration experience with industry, and many of them hold patents.



Through the Industry and Innovation program, the Center is:

- involving students in industry collaboration and innovation processes;
- forming long-term partnerships with a variety of organizations;
- leveraging industry and NSF/DOE support to address major challenges facing the electricity industry;
- equipping students with the skills needed to be leaders at a national and global level; and
- cultivating collaboration among researchers in academia and industry.

To meet the varying needs of diverse industry partners, CURENT has a tiered membership structure that includes Principal, Full, and Associate levels. Principal and full members are companies and other organizations with direct interests in the Center's core research and ERC-developed technologies. Associate members include those organizations that support the ERC through donated equipment, components, software, and services that are aligned with the Center's mission. All CURENT industry consortium members have access to the Center's state-of-the-art facilities, personnel, students, and research results. Through the collaborative industry model, members can leverage resources while engaging in cutting-edge research and development. Members provide advice on strategic research plans, IP protection, and research direction. To facilitate the transfer of ideas to commercialization and accelerate the IP process, an Intellectual Property Protection Fund (IPPF) has been established.

Recognizing that industry engagement is critical to the Center's success, multiple avenues are in place to connect the ERC with industry members, including:

- Annual Industry Conference
- Short courses and seminars
- Workshops
- Industry residence program
- Student internships
- Web-based portal
- Strategic planning and technology road mapping
- Industrial Advisory Board
- Student Fellowships and Mentoring.

Facilities

The headquarters of CURENT are located on the UT main campus in the Min H. Kao Electrical Engineering and Computer Science Building. CURENT occupies more than 16,000 sq. ft. of space to house the CURENT Hardware Testbed, CURENT Large Scale Testbed, CURENT Multimedia and Visualization Center, and FNET monitoring and visualization lab, as well as general power systems and power electronics lab facilities.

- UT's Kraken, the world's first academic supercomputer to reach petascale capability (supported by NSF) and ORNL's XT5 Jaguar, formerly the world's fastest supercomputer, are both accessible to ERC faculty.
- ORNL's Distributed Energy Communications & Controls (DECC) Laboratory, VERDE (Visualizing Energy Resources Dynamically on the Earth) Laboratory, and the $15M Power Electronics and Electric Machinery Research Facility are accessible to ERC faculty. Many faculty have joint appointments at ORNL and as such have access much like regular ORNL staff.
- RPI's Distributed Generation and Smart Grid Testbed, supported by NY State Foundation and Power Grid Control Laboratory, are being used in ERC testbed and system research activities.
- At Northeastern University, the Electric Power and Energy Systems group maintains three laboratories: the Power Systems Lab, the Power Electronics and Motion Control Lab, and the Energy Processing Lab. These are conducting research from LED lighting to solar cells to electromechanical and systems.
- Tuskegee University has laboratories used to support classes on power systems and energy conversion and control systems. The Power Systems Lab has motor-generator sets, transformers, relays, transmission line model sets, and three-phase power supplies.

Min H. Kao building

Center Configuration, Leadership, Team Structure

CURENT is a collaboration between academia, industry, and national laboratories. The Center consists of a lead institution, the University of Tennessee, with three core domestic partnering universities: Northeastern University, Rensselaer Polytechnic Institute, and Tuskegee University. All four universities are known for their strong power programs, and the strengths of their individual research programs is the core of the research at CURENT.

Over 30 faculty members from academic backgrounds that include engineering, economics, and sociology have come together from various institutions to make up the core research group in CURENT. The major research thrusts are distributed by campus and faculty's research focus.

Center Headquarters

CURENT Engineering Research Center
555 Min H. Kao Building
University of Tennessee
1520 Middle Drive
Knoxville, TN 37996
Phone: (865) 974-9720
Fax: (865) 974-9723
info@curent.utk.edu

Web: http://curent.utk.edu

Center Director: Kevin Tomsovic
865-974-9720 • tomsovic@utk.edu

Deputy Director: Yilu Liu
865-974-4129 • liu@utk.edu

Technical Director: Fred Wang
865-974-2146 • fred.wang@utk.edu

UT Campus Director: Leon Tolbert
865-974-2881 • tolbert@utk.edu

Education & Diversity Director: Fangxing (Fran) Li
865-974-8401 • fli6@utk.edu

Education & Diversity Co-Director: Chien-fei Chen
865-974-3787 • cchen26@utk.edu

Director of Innovation and Industry: Tom King
865-974-0627 • tking33@utk.edu

Industrial Liaison Officer: Brad Trento
865-974-4799 • btrento@utk.edu

Northeastern University Campus Director: Ali Abur
617-373-3051 • abur@ece.neu.edu

Rensselaer Polytechnic Institute Campus Director: Joe Chow
518-276-6374 • chowj@rpi.edu

Tuskegee University Campus Director: Greg Murphy
334-727-8995 • gvmurphy@tuskegee.edu