Smarter, Secure, More Sustainable

POWER
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The National Academy of Engineering has called the North American power grid “the supreme engineering achievement of the twentieth century.” More than 40% of primary energy consumption in the United States is delivered through the nation’s electricity generation, transmission, and distribution infrastructure. However, today’s electricity grid faces many challenges, including aging components, a lack of robust, real-time communications, and an increasing demand for efficient integration of renewable energy sources.

The average power plant was built 30 years ago, and 70% of transmission lines are more than 25 years old. Outdated equipment and a lack of automated control over local electricity delivery result in the waste of 60% of the country’s primary energy. Even as older systems become less reliable each year, the country continues to experience extreme weather events, such as hurricanes, tornadoes, and ice storms, that damage the electricity grid and cause costly, widespread outages.

A next-generation, digital, communicative “smart” grid will require new operational and planning capabilities and substantial infrastructure investment over several decades to meet the country’s energy goals. To address these challenges, the President’s Climate Action Plan has called for “Expanding and Modernizing the Electric Grid.”

The Department of Energy’s (DOE’s) Oak Ridge National Laboratory (ORNL) Sustainable Electricity Program is working with industry and academia to modernize the electric grid through research and development focused on:

- Enhancing real-time visualizations and data analysis to isolate grid failures and quickly restore power
- Strengthening cyber security for a computerized grid
- Deploying low-cost sensors to monitor grid health
- Hardening infrastructure with advanced conductivity
- Developing microgrid technologies that localize energy management
- Integrating and utilizing renewable energy more effectively
- Controlling power flows with advanced technologies

Delivering Innovation
Big Data and Data Analytics
Leveraging the power of ORNL’s world-class high-performance computing resources, researchers are developing cutting-edge analytic software that can quickly manage large amounts of data and package information in performance assessments useful to utility providers, such as geospatial models for state, power flow, frequency, and voltage. ORNL staff are working with utilities on developing data architectures for the future grid.

Ultrascale Computing for Power Systems
ORNL is developing the capability to simulate electric power systems at geographic scales of sufficient scope of electrical, mechanical, control, and communication components to explore monitoring, control, and cyber security issues on the smart grid.

Cyber Security and Risk-Based Tools
Severe weather is not the only risk to the electric grid. Cyber attacks can cause blackouts intended to compromise security or economic transactions. ORNL’s expertise in encryption, embedded and wireless systems, interoperability testing, and resilient controls has led to more stringent information security and hardware methods to deflect cyber attacks.

Beholder
In partnership with General Electric Research, ORNL is developing technology that exploits fine-grained timing data collected from remote network and SCADA (supervisory control and data acquisition) devices to reveal the presence of software and network intrusions. The Beholder technology is focused first on detecting timing patterns that indicate anti-detection methods, and second, on detecting significant deviations from a device baseline. For the latter, ORNL researchers have been investigating phase-space dissimilarity measures. Initial experiments have confirmed the general feasibility of this approach; ORNL is now working to develop a system for testing and detection under realistic conditions in the field, and to measure any potential impacts of running Beholder upon availability and reliability.

Cyber Security Econometrics System
The Cyber Security Econometrics System assesses grid vulnerabilities and provides goals and milestones for protecting control systems through quantitative indicators of reliability, performance, and safety. This technology provides courses of action that reduce the most risk for the lowest cost.

Hyperion
ORNL’s Hyperion system, developed in partnership with EnerNex and Sensus, analyzes controlled software embedded in devices on the grid for malware and other vulnerabilities.

Visualization Platforms
Visualizations mapping storm systems, grid vulnerabilities, and power failures can help direct emergency response teams as grid disturbances occur and utilities rapidly restore power to customers. On the other end of the grid, energy usage visualizations can help customers manage their energy cost and footprint.

CoNNECT
CoNNECT helps customers visualize their energy consumption by developing a utility-user interface so customers can access their energy usage data in useful packets of information. This interface will allow customers to compare
their energy use with that of other customers in buildings of similar age and construction, score their energy use over time, and correlate their data with weather records.

Visualizing Energy Resources Dynamically on Earth (VERDE)

VERDE overlays information as it is delivered from the electricity grid with weather models and energy infrastructure maps to convey the real-time status of the grid for contingency analysis.

Operational Tools and Synchrophasors

GridEye

In partnership with the University of Tennessee, ORNL uses a unique, wide-area grid monitoring network to continuously observe grid performance. GridEye’s low-cost, easy-to-install monitors are deployed across the globe and measure dynamic responses, such as frequency, voltage, and phase angle, that indicate major disturbances on the grid.

Modeling

Power System Simulator for Engineering (PSSE)

Executable on a single desktop computer, PSS/E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance, including the areas of power flow, optimal power flow, balanced or unbalanced fault analysis, dynamic and extended term dynamic simulation, transfer limit analysis, and network reduction.

Eastern Interconnection Planning Collaborative (EIPC)

To predict grid performance as more renewable energy sources are introduced on the grid, ORNL and major utility partners are developing models that represent three levels of new grid infrastructure and wind penetration in 2030. ORNL’s partners on EIPC include utility companies within the Eastern Interconnection, which make up EIPC, and Eastern Interconnection States Planning Consortium.

Model Validation for the Eastern Interconnection

To improve the credibility of simulation results, ORNL is refining the Multiregional Modeling Working Group models by modeling governor deadband and adjusting active governor ratio and load composition in order to match measured Eastern Interconnection frequency responses. This includes building validated base cases for future Eastern Interconnection grids to better study the impact of renewable generation.

Faster than Real-Time Wide-Area Protection and Control

ORNL is applying the latest computational algorithms and parallelization techniques to enable faster than real-time power system dynamic simulations. These will evaluate existing and develop new methods for time-domain simulations of power system dynamics using numerical integration of the nonlinear transient differential equations. This approach can help predict and prevent system disturbance.

Dynamic Protection Planning Simulator with CAPE and PSS/E Models

The Dynamic Protection Planning Simulator is a consolidated planning and system protection model for assessing high penetration of renewable generation and impact on protective relaying schemes during power system disturbances. This advanced modeling system consolidates planning dynamics (PSS/E) and Electron International Inc’s Computer Aided Protection Engineering (CAPE TS) link to identify vulnerabilities and provide a platform for future research in detection of imminent disturbance and cascading events.

MOVARTI

With a changing mix of energy generation sources, including more natural gas, renewable energy, and distributed energy systems, utilities face greater uncertainty when planning and operating the power system. As new generation sources come online at the same time older coal-fired units are idled or retired, utilities are seeing an increasing number of voltage issues across their service territories. Companies are making investments in technologies, such as reactive power (or VAR) resources like static VAR compensators, without a clear picture of what the future looks like. ORNL is working on the MOVARTI tool that will help determine the value of VAR resources to assist in the decision making process for utilities.
Enhanced Grid Components

New materials, such as high-temperature superconductors and superhydrophobic surfaces, are improving cables and conductors that deliver electricity throughout the grid. Strong winds, ice, and floods can dismantle power lines and cause power outages while lines are being repaired. Superhydrophobic surfaces being developed by ORNL researchers are water-repellant, mitigating ice buildup and damage to conductors.

Advanced Conductors

ORNL is developing advanced connectors to connect cables that span hundreds of miles. ORNL and the Electric Power Research Institute are testing the lifetime service performance of these connectors.

Low-Cost Sensors with Additive Systems

By embedding sensors throughout the electric delivery system, utility companies can monitor grid health. Using additive manufacturing, ORNL is developing sensors that can be printed, sprayed, or deployed much like barcodes, which reduces cost and increases the availability of these electronics. Sensors can identify voltage issues and power failures as soon as they occur, as well as fuse performance analysis with weather and climate indicators, making regular grid maintenance and disaster response more efficient and cost-effective.

Microgrid Controls

Microgrids are local electricity grids that disconnect from and resynchronize with the utility grid as needed. They provide islanded operation during utility outages and energy management of local power sources, including renewable sources like solar panels and fuel cells. ORNL is developing microgrid controllers and testing to demonstrate the value of microgrid systems.

Grid-less Solutions and Restoration

Grid disruptions such as extreme weather events or cascading power failures can leave homes and businesses without power for weeks at a time. ORNL is tackling the challenge of providing reliable, resilient, and responsible energy use in buildings through an integrated approach to electricity generation, distribution, and consumption.

This research will foster a built environment of integrated energy systems that efficiently transact with existing centralized grids while also providing increased resiliency and reliability, and effectively provide reliable energy services to buildings where no centralized grid is available, that is, “off-grid.”
Power Electronics

ORNL houses DOE’s largest power electronics laboratory for electricity grid applications, facilitating research that has dramatically progressed the technology of advanced inverters, dc-dc converters, and high-voltage, high-speed power systems. Among these research priorities, researchers are using new magnetic materials to build more efficient, less expensive saturable reactors, which convert dc electricity from energy storage devices like fuel cells into usable ac electricity for utility customers. They are also developing Accelerated Lifetime Testing and automated characterization techniques to facilitate high-voltage power electronic devices and their integration into the grid.

Power Flow Control Systems

Inability to control power flow can lead to overloading transmission lines, cutting corners on operational security, and underutilizing grid capacity. In fact, the grid typically uses less than 50% of total available capacity. To address these problems, ORNL is developing a new type of power flow controller that improves reliability by using a magnetic amplifier to isolate power electronics that direct flow from the high voltage and current power flow on the main circuit. The prototype is significantly cheaper than current flexible ac transmission system devices and eliminates the need for costly, high-maintenance superconducting equipment.

Energy Storage

Working with energy storage vendors, ORNL is testing small-scale energy storage units, such as recycled (or secondary-use) electric vehicle batteries and redox flow battery systems. ORNL developed a testing platform at its Distributed Energy Communication and Controls (DECC) Laboratory to demonstrate the ability of a 25 kilowatt-hour (kWh)/50 kWh energy storage unit designed by partner ABB and composed of five used Chevy Volt batteries from General Motors. This and additional energy storage projects at DECC will evaluate the service life of secondary-use systems and their value on the grid.
**Powerline Conductor Accelerated Test (PCAT) Facility**

The objective of the PCAT facility, a transmission test facility, is to accelerate the commercialization of new conductors for power system transmission lines by testing conductors at their rated temperatures and currents in an outdoor environment after they have been installed and tensioned to the manufacturer’s specifications—a capability that does not exist elsewhere in the United States. The test line is 1,200 ft long, resulting in a 2,400 ft loop of conductor connected to a dc power supply rated at 5,000 analog-to-digital convertor, or Adc, and 400 volts of direct current, or Vdc. Conductor tests—including knee-point curve measurement, emissivity measurement, current and temperature, current ramp, and thermal/mechanical cycling tests—measure conductor performance and weather condition parameters on a one-minute basis.

**Distributed Energy Communications and Controls (DECC) Facility**

To improve system flexibility for meeting daily energy demands and ensuring energy delivery during emergencies, ORNL researchers with the DECC Laboratory are developing tools to support distributed energy resources, such as microturbines and fuel cells, so the microgrid can provide local power with greater efficiency and reliability. The DECC Laboratory is a unique ORNL-owned and operated 13.8 kV-distribution system for studying microgrid energy management, protection schemes for renewable generation, energy storage, and advanced sensors and controls.

**ORNL Cable Test Development Laboratory**

Leveraging ORNL’s experience in conducting research on large-scale high-voltage equipment such as ac and dc cables, transformers, and fault current limiters, the Cable Test Development Laboratory is used to safely test prototype equipment before field installation. This joint ORNL and Southwire facility is the only one at a DOE national laboratory with the needed power supplies and nitrogen circulation for full-scale prototype testing of high-temperature superconducting equipment, including tests for cables and cable components, power supplies, terminations, joints, and cryogenic systems.

**ORNL High-Voltage Dielectrics Research and Testing Facility**

To meet challenges posed by high-voltage conditions, the ORNL High-Voltage Dielectrics Research and Testing Facility integrates expertise in modeling, novel materials fabrication, and high-voltage testing with testing systems that operate under realistic extreme conditions—including the ability to characterize dielectric performance from 800° Celsius to cryogenic temperatures under a variety of pressure conditions ranging from high-vacuum to 15 atmospheres.
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