Grid Modernization

Resilient, Secure,
More Sustainable
Electricity

OAK RIDGE
National Laboratory

Delivering Innovation

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 electric grid faces many challenges, including aging components, the threat of terrorism, and an increasing demand for efficient integration of renewable energy sources.

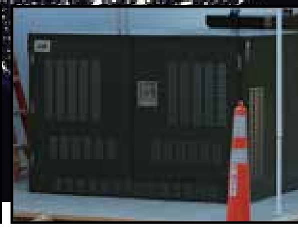
The average power plant was built 30 years ago, and 70% of transmission lines are more than 25 years old. Even as older components become more brittle each year, the country continues to experience extreme weather events, such as hurricanes, tornadoes, and ice storms, that challenge the electric grid and cause costly, widespread outages.

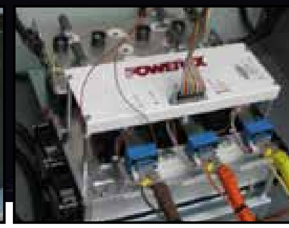
A next-generation, digital, communicative "smart" grid will require new operational and planning capabilities and substantial infrastructure investment over several decades to meet the country's energy goals. To address these challenges, the Department of Energy has established the Grid Modernization Initiative.

Through this effort, Oak Ridge National Laboratory's (ORNL) Sustainable Electricity Program is working with industry and academia to modernize the electric grid through research and development focused on:

- Deploying low-cost sensors to monitor grid health
- Enhancing real-time visualizations and data analysis to isolate grid failures and quickly restore power
- Strengthening cybersecurity for a modern grid
- 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
- Using unmanned aerial systems (UASs) to inform electric system restoration activities

Situational Awareness and Analysis





Low-Cost Sensors with Additive Systems

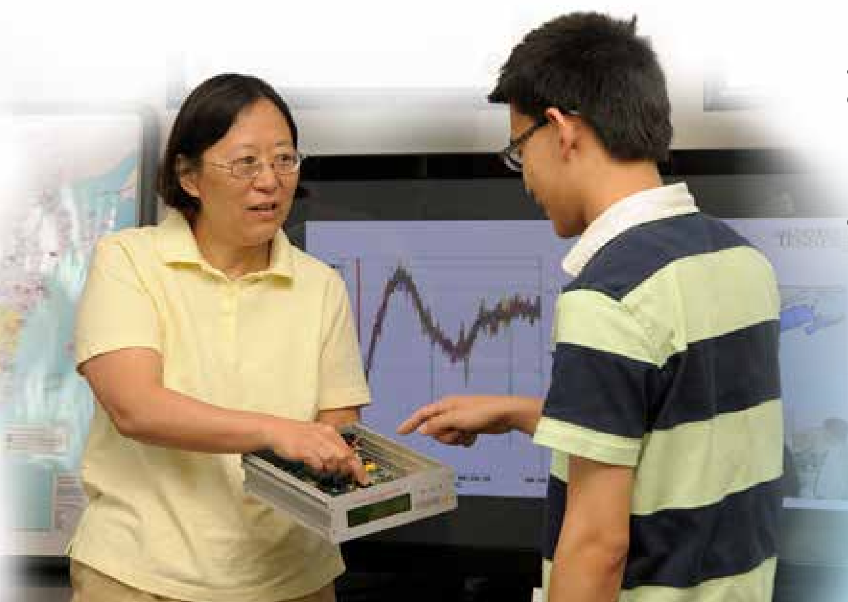
By embedding sensors throughout the electric delivery system, utility companies can monitor grid health. Using additive manufacturing, ORNL is developing sensors that can be printed, sprayed, or deployed much like barcodes, which reduces cost and increases the availability of these electronics. Sensors can identify voltage issues and power failures as soon as they occur.

When fused with other performance and weather data, novel sensors make regular grid maintenance and disaster response more timely and cost-effective.

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.



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 cybersecurity issues on the smart grid.

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 and enhance communications with first responders in other critical infrastructures in outage situations.

EAGLE-I

From coast to coast, the United States relies on electricity, natural gas, petroleum, and coal to supply continuous energy. Monitoring the energy sector for situational awareness requires a seamless system, capable of providing accurate, real-time data. Developed by the Department of Energy and supported by ORNL, EAGLE-I (Environment for Analysis of Geo-Located Energy Information) watches the nation's energy sector in real time. The centralized platform system monitors power distribution outage for more than 110 million customers, including wide-area situational awareness and analysis.

Modeling

PSSE, EIPC and Model Validation

PSSE (Power System Simulator for Engineering), a General Electric system, is an integrated and interactive program for simulating, analyzing, and optimizing power system performance. EIPC (Eastern Interconnection States Planning Consortium) develops models that represent three levels of new grid infrastructure and wind penetration in 2030. ORNL's EIPC partners include utility companies within the Eastern Connection. ORNL continues to refine Multiregional Modeling Working Group models by modeling governor deadbands and adjusting load composition to match measured Eastern Interconnection frequency responses.

Faster than Real-Time Wide-Area Protection and Control

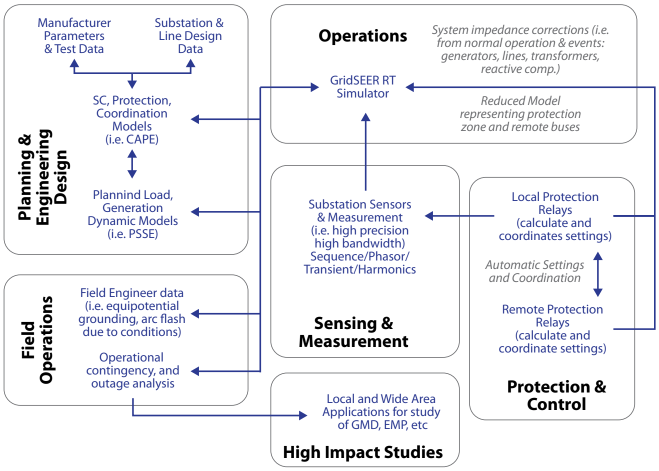
ORNL is applying the latest computational algorithms and parallelization techniques to enable faster than real-time power system dynamic simulations. These will evaluate existing and develop new methods for time-domain simulations of power system dynamics using numerical integration of the nonlinear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

Adaptive Dynamic Protection Planning Simulator

The adaptive dynamic protection planning simulator is a consolidated protection model integrated into real time hardware. The R&D tool provides a platform for future research in the detection of imminent disturbance cascading from power system events. This project extends the PC based simulation with a hardware based protection device which can internally simulate a reduced dynamic model of the simulations to develop a protective relay device that can automatically set and coordinate with remote zone terminals.

Management and Optimization of VARS for Future Transmission Infrastructure (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 capital budget allocation process for utilities.



Cybersecurity 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 Technology

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.

Timing Authentication Secured by Quantum Correlations (TASQC)

The Timing Authentication Secured by Quantum Correlations (TASQC) project develops and demonstrates a system of ground-based timing and communication beacons featuring security that is enhanced by geographically distributed quantum correlations (the expected change in physical characteristics as one quantum system passes through an interaction site) taking full advantage of the direction of information flow for power systems management. Unlike GPS-based timing schemes, this system will feature transmitted timing signals that are a priori unknown, making them very difficult to spoof. In addition, the signals will include quantum correlations that will provide several avenues for authenticating not only the timing signals, but also power systems data (e.g., sent from a phasor measurement unit (PMU) to a substation) and other communications tasks. The system will offer the improved security afforded by the techniques of quantum communication through a relatively modest infrastructure that will be able to support not only a suite of increasingly secure timing protocols, but also a wide range of authenticated communication tasks. Without the need to rely on GPS signals, utilities will be able to establish complete end-to-end control of security for time-sensitive data.

Flexible, Robust and Hardened Infrastructure

Microgrid Controls

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

AMIE

ORNL's Additive Manufacturing + Integrated Energy (AMIE) 3D-printed home and hybrid vehicle project encompasses the tiny home and vehicle, solar arrays for onsite power generation, wireless vehicle charging, a secondary battery pack to store energy, and a version of Complete System-Level Efficient and Interoperable Solution for Microgrid Integrated Controls (CSEISMIC) to control the flow of energy between all those components and the utility grid.

Software-defined Intelligent Grid Research Integration and Development (SI-GRID) facility

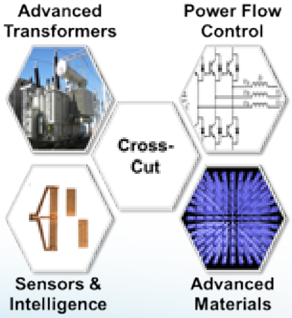
ORNL has developed an open, low-voltage microgrid research platform designed to accelerate the exploration and transition of microgrid-related science from the laboratory to the field. It is being used to develop and rapidly prototype technologies associated with microgrids, including power electronics– based converters; generation technologies; machine-based systems; energy storage; protection; communications; control; optimization; standardization; and integration of distributed energy resources, buildings, and vehicles; as well as modeling, simulation, and cybersecurity. All system components operate at or below 50 V, providing a safe environment for accelerated R&D, but scaled to be analogous to the physics of larger systems.

Industry Partnerships

ORNL and the Chattanooga Electric Power Board (EPB) are working together to learn how to best apply communications, sensors, controls and other technologies so a power grid can function more autonomously and reliably as it grows and becomes more complex. ORNL is leading the effort with eight other national laboratories to collect real-time sensor data so the grid system immediately sees fluctuations and can balance the electrical load. ORNL has worked with EPB to install sensor arrays at eight locations around the municipal utility's 600-square-mile territory, mostly at substations. In addition to the stationary sensor arrays, EPB and ORNL are studying how sensors installed on drones can help improve system reliability.

Advanced Grid Components

New materials, such as high-temperature superconductor wires developed by ORNL, have the potential to improve the efficiency of cables and conductors that deliver electricity throughout the grid. Similarly, anti-icing water-repellent superhydrophobic coatings can enhance grid resiliency by mitigating the damages from ice storms and weather events. Currently, ORNL is leveraging its advanced manufacturing capabilities to evaluate the feasibility of using additive manufacturing process control and scan strategies to produce grain-oriented silicon steel. Development of such technology will help address the critical issue of domestic manufacturing of power transformer cores.



Transformer Resilience and Advanced Components

ORNL's Transformer Resilience and Advanced Components (TRAC) program accelerates modernization of the grid by addressing challenges with critical grid materials and components. As the grid evolves to enable a more resilient energy future with a geographically diverse energy mix, ongoing research, development, demonstration (RD&D) and testing are needed to understand the physical impact these changes have on a variety of grid equipment and to encourage the adoption of new technologies and approaches. Development of advanced components will provide the physical capabilities required in the future grid and help avoid "lock-in" of outdated technologies that are long-lived and expensive.

Power Electronics, Power Flow Control Systems and Energy Storage

Power Electronics

ORNL houses one of DOE's largest power electronics laboratories for electric grid applications, facilitating research that has dramatically progressed the technology of advanced inverters, DC-DC converters, and high-voltage, high-speed power systems. Researchers are using new magnetic materials to build more efficient, less expensive devices to convert DC electricity from energy storage devices, solar panels, and fuel cells into usable AC electricity for utility customers. ORNL also has an in-house packaging facility researchers use to develop advanced high efficiency reliable power converters starting from bare wide bandgap semiconductor dies allowing vertical integration for power electronics hardware research and development.

On the transmission side, ORNL is building an innovative power hardware-in-the-loop hybrid transmission grid emulator named "Flexible Intelligent Real-Time DC-AC Grid Emulator (FIRE)." The FIRE platform provides a grid modernization tool to design advanced large-scale DC macrogrids/links embedded in to the existing AC system that enhances the reliability and security of the existing AC grid. The FIRE platform consists of power electronics hardware modules that are present in the hybrid grids and enables validation of advanced components in hybrid grids.

On the distribution side, researchers are involved in developing energy routers and smart inverters that enhance the stability of the grid-connected power electronics. ORNL is also working on wired and wireless vehicle to grid (V2G) system demonstrations for further grid and microgrid support from plugin vehicles.

Energy Storage

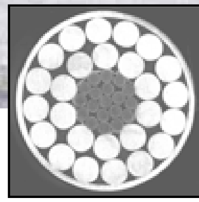
Working with Spiers New Technologies (SNT) and Habitat for Humanity, ORNL is developing and prototyping an energy storage system composed of repurposed electric vehicle batteries. Utilizing commercially off the shelf inverter technologies and repurposed Nissan Leaf batteries from SNT, ORNL developed an integration strategy and control system for a low-cost energy storage system for a residential community. As a proof of concept, ORNL constructed a demonstration unit through an internally funded Advanced Manufacturing and Integrated Energy project. The final unit, now under construction, is planned for deployment in 2018.

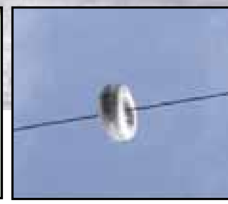
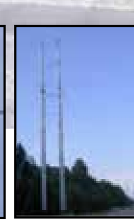
Power Flow Control Systems

To modernize and control the grid, new low-cost, high-efficiency, and reliable power electronics (PE)-based power flow devices using wide bandgap devices are needed. Two paths to advancing these devices are being pursed at ORNL: using PE-based devices to directly control the power flow, and using hybrid, PE-based power flow technologies to control electromagnetic devices like transformers and reactors, which in turn control the power flow and fault current. Both paths require extensive PE research to utilize the superior properties of wide bandgap devices compared with their silicon-based counterparts.

Inability to control power flow can lead to overloading transmission lines, reducing operational flexibility, and underutilizing grid capacity. In fact, because of the growth margin inherent in long-life components, 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 control power flow on the AC circuit. The prototype is significantly cheaper than current flexible AC transmission system devices. A variance of this technology is being investigated to develop a tapless transformer where the voltage can be continuously regulated without a mechanical tap changer. Yet another variance can lead to a current limiter that will eliminate the need for other types of costly, high-maintenance fault current limiter equipment.

ORNL Test Facilities




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 platform is 1,200 ft long, resulting in a 2,400 ft loop of conductor connected to a dc power supply rated at 5,000 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

ORNL researchers with the DECC Laboratory test the novel equipment and systems that have been developed by ORNL and others. DECC supports the testing of distributed energy resources, such as PV panels and energy storage devices. 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.

For more information contact

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https://www.ornl.gov/research-area/electricity-and-smart-grid

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