Summary of the Advanced Applications Research and Development Activity Area

Developing and demonstrating tools to monitor and control the grid with advanced analysis, visualization, and situational awareness tools

U.S. DEPARTMENT OF ENERGY | Electricity Delivery & Energy Reliability
Transmission Reliability and Renewables Integration Program

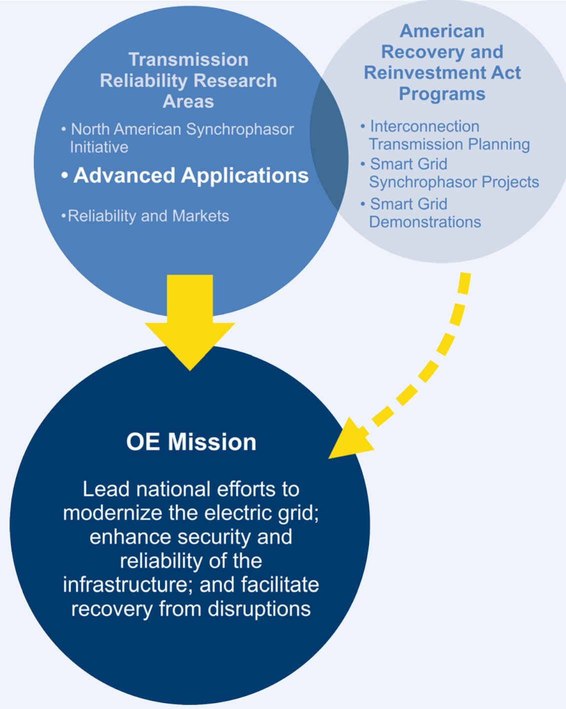
The Department of Energy (DOE) is actively involved in leading the development of advanced applications and tools to more effectively operate the electricity delivery system by enabling advanced analysis, visualization, monitoring and alarming, and decision support capabilities for grid operators.

These applications use—and greatly increase the value of—data coming from high-resolution electrical measuring devices known as phasor measurement units (PMUs), whose deployment is being facilitated by the North American SynchroPhasor Initiative.

The advanced applications research and development activities of DOE and its industry partners are a key component of the success of American Recovery and Reinvestment Act (ARRA) programs. By the time the ARRA projects are completed in 2014, several of these applications are expected to be fully integrated into control rooms across the nation.

DOE is funding research and development (R&D) for advanced applications in two principal areas:

- **Real-time grid operations applications** to provide wide-area visualization and increased state awareness
- **Planning and off-line applications** to improve system planning and analysis, including power system performance baselining, event analysis, and model validation.

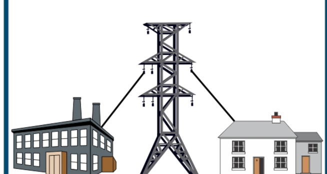
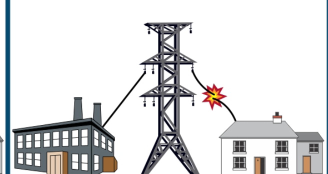
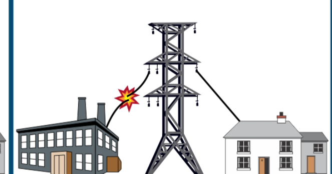
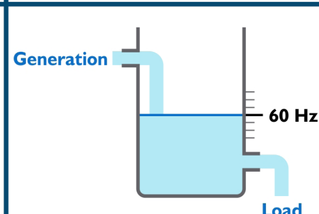
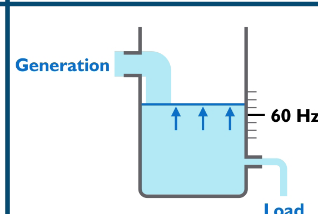
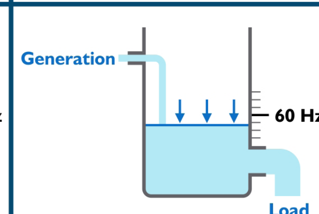


Advanced Application Development is one of three key activity areas within the Transmission Reliability and Renewables Integration Program. These activities have a collaborative role with American Recovery and Reinvestment Act (ARRA) programs in helping to improve grid monitoring and operations and ultimately achieve the OE mission.

Real-Time Grid Operations Applications

Today, most power system operators have very little visibility into electricity system operations. New real-time applications will provide greater visibility from PMUs, enabling immediate alarming, analysis, visualization, and decision support capabilities. These capabilities improve operators' ability to see and understand in real time what is happening on the bulk power system; anticipate potential problems; and identify, evaluate, implement, and assess remedial measures. This capability is becoming even more critical as the power system integrates the growth of intermittent resources.

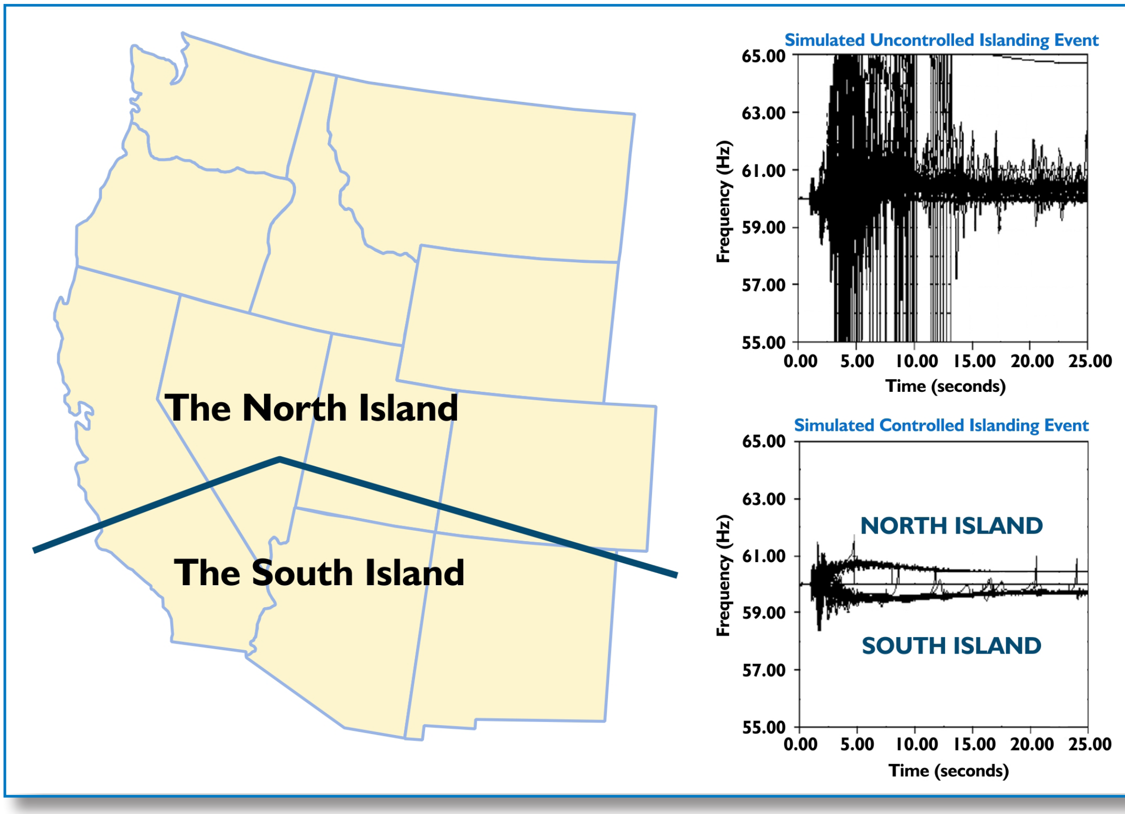
Table to right: Electric power generators in the United States operate by rotating 60 times a second, or 60 Hertz (Hz). Even in small regions, a large number of generators may work together to provide customers with power. If there is a disruption in the flow of power in this system, the grid can quickly become unstable. This can happen due to a deviation from 60 Hz. This instability, if not properly addressed, can damage power equipment and escalate to cause severe, widespread outages. Applications being developed and deployed by the DOE are working to minimize these issues, ultimately saving time and money and increasing reliability.

Situation:	Inflow=Outflow	Inflow>Outflow	Inflow<Outflow
Example:	Grid operates as designed 	Sudden loss of load 	Sudden loss of generation 
Analogy to water flow:			

Example Project – Western Electricity Coordinating Council (WECC) Adaptive Islanding

When a power system is subjected to a large disturbance, which could result in cascading outages, it is critical to mitigate the impact and correct the system to an acceptable operating condition.

Controlled islanding, which intentionally separates a bulk power system into several self-sustaining electrically isolated parts after a severe contingency, provides an option of last resort to prevent the spreading of cascading outages with a limited loss of load and generation. If a system is subjected to a large disturbance and the subsequent control and protective actions are not successful in preventing cascading outages, the system eventually breaks up into several parts as a result of uncontrolled islanding.



In extreme situations, early separation using a controlled islanding strategy could also prevent uncontrolled islanding and minimize disruptions.

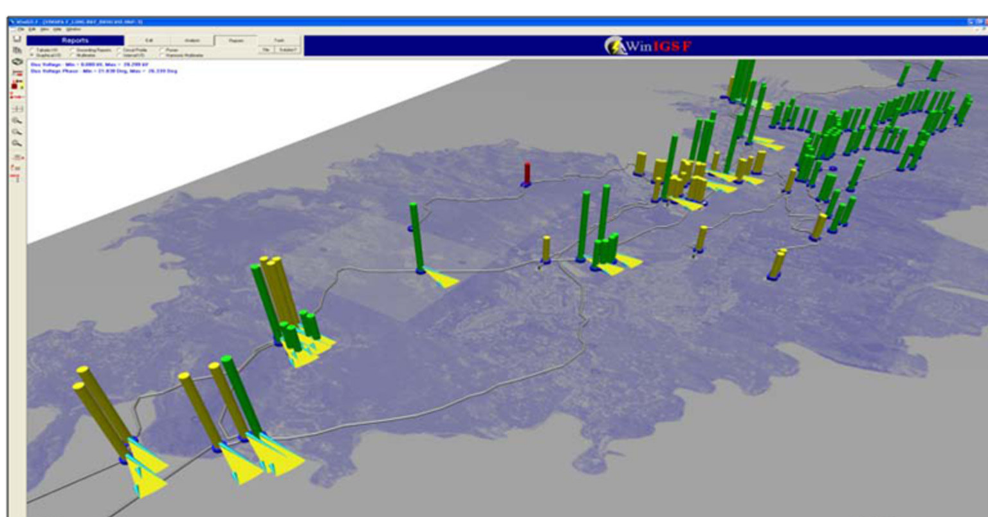
The images above illustrate through a simulated extreme contingency in WECC how controlled islanding keeps generator frequencies in safe ranges relative to uncontrolled islanding. In the islands formed, frequencies and voltages in the transmission network are within an acceptable operating range, although services would be slightly degraded. Compared to uncontrolled islanding, controlled islanding results in less load shedding, in tripping of fewer generators, and in lower blackout probabilities.

Example Project – SuperCalibrator: A Dynamic State Estimator

Through funding from the Department of Energy, researchers at Georgia Institute of Technology are working with the New York Power Authority and the US Virgin Islands Water and Power Authority to develop an advanced dynamic state estimator, called the SuperCalibrator, for their electrical grids. The SuperCalibrator uses software to model a section of the electrical grid to provide an accurate estimate of its current state via an advanced state estimator. The dynamic state estimator is executed up to 60 times per second, thus tracking the dynamic state of the system. The SuperCalibrator includes many grid components including generators, substations, PMUs, relays, and other components to increase its accuracy and allow maximum benefit from measurements being taken across the grid. This tool will allow grid operators to see, via visualizations such as the image below, what the electrical grid looks like in real time, and can even assist in predicting instabilities much faster than current methods.

This image shows a visualization of the US Virgin Islands using the SuperCalibrator.

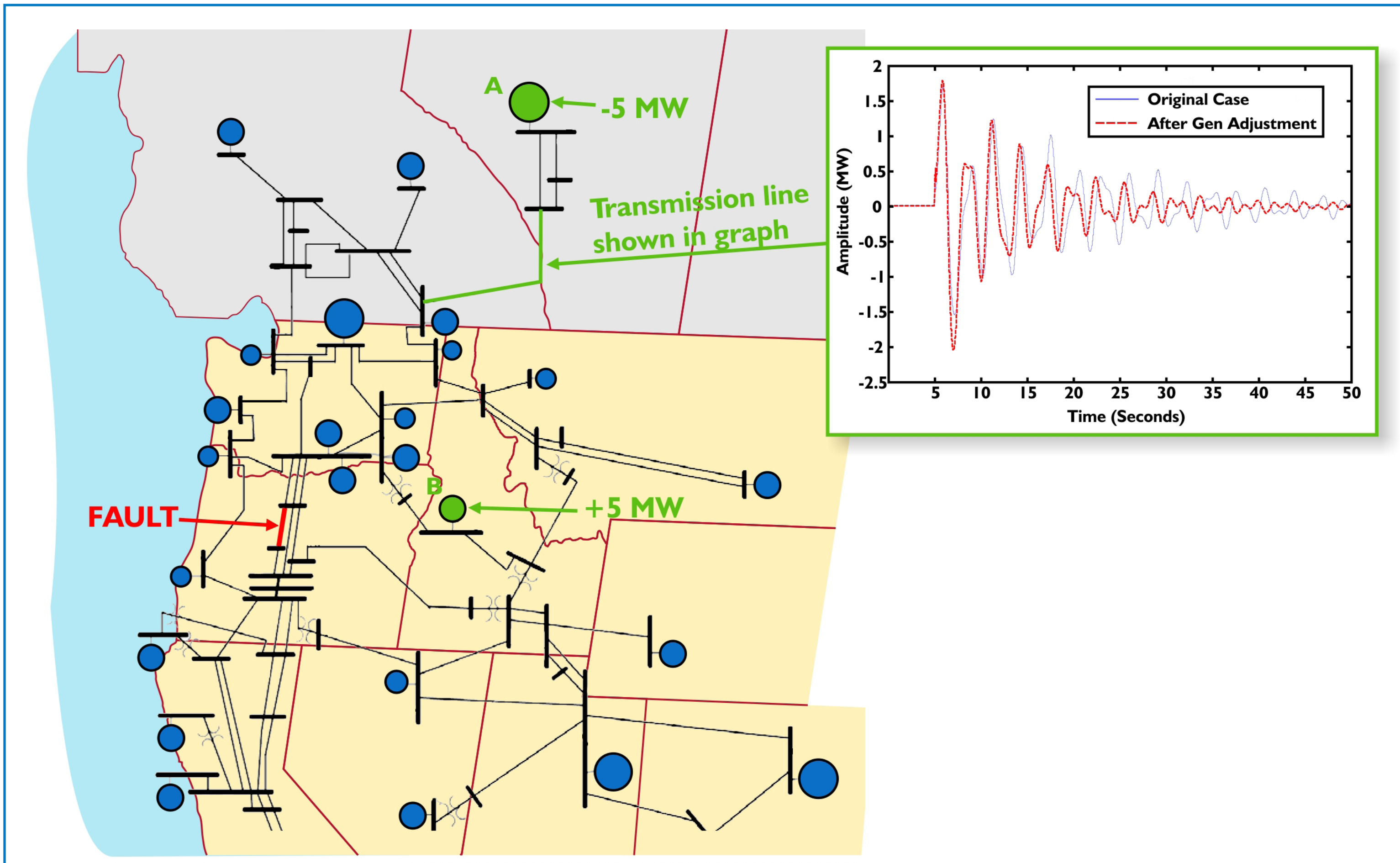
- The heights of the cylinders are proportional to normalized voltage magnitudes at different points. The system has two voltage levels, as shown by the relative heights of the cylinders.
- The voltage phases are indicated by the yellow arcs.
- The colors are user-selected and indicate that voltage is:
  - within 4% of nominal values (green),
  - within 8% of nominal values (yellow),
  - outside of 8% of nominal values (red).



Example Project – Modal (Stability) Analysis for Grid Operations

Researchers modeled the electric grid of the western United States (see figure below) to analyze how to most effectively mitigate oscillations based on faults. This analysis created recommendations which can be used as a guide for grid operators in case an actual fault does occur. For example, the most effective action for generators to take to diminish a fault occurring at the line indicated in the image to the left would be to ramp down generation at Generator A and ramp up generation at Generator B (shown in green circles).

The graph below shows the simulated effect on the transmission line and after implementing the modal analysis recommendation. The oscillation response diminishes more quickly after implementing the recommended adjustment.



Planning and Off-line Applications

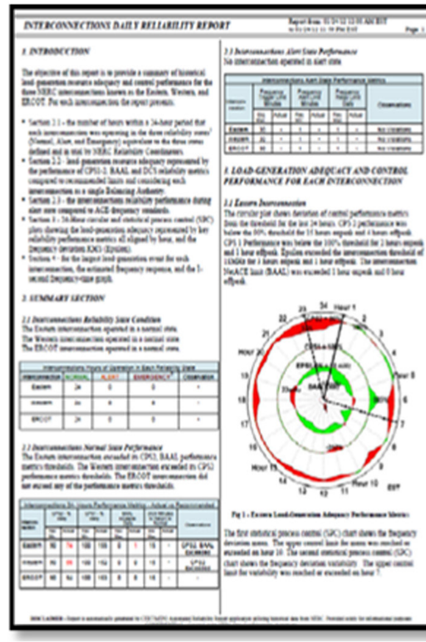
DOE is funding research in developing planning and off-line applications to improve system planning and analysis, including power system performance baselining, event analysis, and model validation. This work is important for organizations responsible for maintaining wide-area reliability (such as the North American Electric Reliability Corporation [NERC]) and for regulatory agencies (such as the Federal Energy Regulatory Commission [FERC]).

The electricity delivery system is an extremely complicated system, and maintaining reliability in the event of contingencies is therefore an equally complicated problem—one that requires commensurate planning, particularly with the use of building models. A historical baseline must be identified, so that deviations from the baseline can be indicated to grid operators to allow rapid corrective action to be taken. Additionally, to improve the system, as well as models of the system, it is important to understand what exactly went wrong after an event when the system was compromised or failed. This is known as post-contingency analysis.

Example Project – Automated Reliability Reports

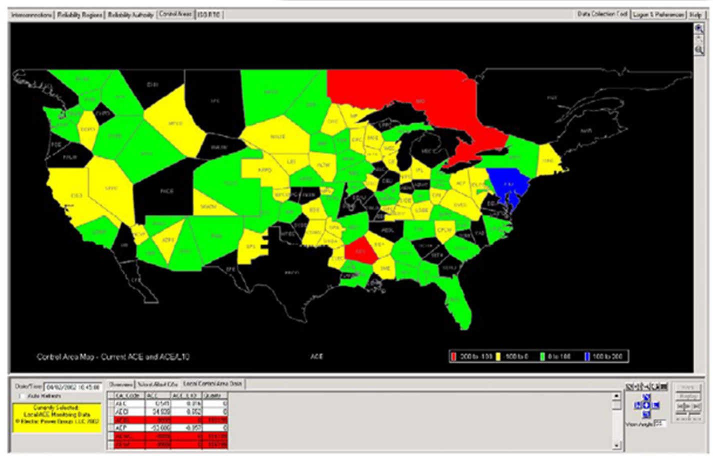
DOE is conducting research on producing Automated Reliability Reports (ARRs) on load-generation control and grid reliability performance for post-disturbance conditions for interconnections between regions on the electricity grid. These reports can then be used to assess reliability problems, identify troubling trends before long-term damage occurs, and help refine and define reliability standards.

The research is identifying the value of different load-generation control and transmission metrics, such as system frequency, voltage limits, as well as thresholds for these quantities to alert a grid operator of a potentially damaging condition/deviation. This type of research helps to define the functional requirements, data needs, performance metrics, and visualizations of ARRs for tracking interconnection grid reliability performance in the short term (i.e., daily or weekly) and reliability standards compliance and adequacy in the long term (i.e., monthly, quarterly, and yearly).



Right: An example of an Automated Reliabilty Report.

Below: An example screen shot of the Resource Adequacy tool.



The ARRs research builds upon DOE's Resource Adequacy (RA) and Frequency Monitoring and Analysis (FMA) tools. The RA and FMA tools use real-time SCADA and sub-second phasor data to alert reliability coordinators of conditions that jeopardize reliability. They also make available data related to abnormal events so that operators can quickly identify root causes, which helps to avoid time-intensive investigations and related delays. These advances provide sufficient time to work with out-of-compliance control areas to correct impending problems in real time, reducing the chances of unplanned blackouts. The three applications (ARRs, RA and the FMA tools) work together to provide grid operators with information needed to operate the system more effectively and reliably, and regulators with critical, archived operations information for improving existing reliability standards, or defining new reliability standards.

Applications like these have already helped NERC and regional entities to monitor compliance with reliability standards on the bulk electric power system, take preventive actions, analyze events, and identify current reliability standards' inadequacies.

Further reading

Office of Electricity Delivery and Energy Reliability: *http://energy.gov/oe/office-electricity-delivery-and-energy-reliability*.

Recovery Act Smart Grid Programs: *http://www.smartgrid.gov/recovery_act*.

"Real Time Application of Synchrophasors for Improving Reliability". NERC report. *http://www.nerc.com/docs/oc/rapirtf/RAPIR%20final%20101710.pdf*

"MANGO – Modal Analysis for Grid Operation: A Method for Damping Improvement through Operating Point Adjustment". Huang, Z. et.al. *http://certs.lbl.gov/pdf/pnnl-19890-mango.pdf*.

"Controlled Islanding Demonstrations on the WECC System". Xu, G. et.al. *http://ieeexplore.ieee.org//xpls/abs_all.jsp?arnumber=5457981*.

Consortium for Electric Reliability in Transmission Systems: *http://certs.lbl.gov*

About the Transmission Reliability Program

The Transmission Reliability Program was established by Congress in 1999 to support a national laboratory/electricity industry partnership to conduct research on the reliability of the nation's electricity delivery infrastructure during the transition from regulated markets to competitive markets under restructuring. Competition and market forces are creating an exponential increase in the volume of power transactions and causing the grid to be used in ways for which it was not designed. The Transmission Reliability Program is developing advanced technologies, including information technologies, software programs, and reliability/analysis tools to support grid reliability and efficient markets during this critical transition.