SHAPING THE FUTURE

Innovative approaches to upcoming challenges

Synchrophasors: Pushing the Envelope on Grid Stability

Ensuring grid stability has always been as much an art as a science. Operators in regional control centers monitor system stress by piecing together power flow data gathered from substations by a supervisory control and data acquisition (SCADA) system. This information is fed into a computer model, which then generates a rough estimate of the system's stability. If off-normal conditions start to eat into stability margins, the operators try to identify where the problem lies and take steps to remedy the situation by regulating voltages, rerouting power, or shedding load. Failure to do so can allow a minor localized disturbance to cascade into a regional blackout.

The "art" of stability management is in making effective decisions from an incomplete, inaccurate, or seconds-too-old data set. In the future, synchrophasors will provide a strong boost to the science side of the equation—a change that will be crucial to the successful development of the smart grid.

Super Fast Data in Lockstep

Grid instability is signaled by changes in phase angle—the relationship between voltage and current in ac systems—and comparisons of phase angles at different substations can provide a strong indication of where the trouble lies. Unfortunately, conventional phase angle monitors sample data only every 2–4 seconds, and a lack of synchronization makes it difficult to determine which phase shifts occurred first and which were the slightly later effects of the early disturbances.

This uncertainty can be eliminated by synchrophasors—synchronized phase data taken by phasor measurement units (PMUs) installed at substations and other power delivery junctions. These units sample phase angle—as well as power flow, voltage, and frequency—30 times a second, synchronizing the data across the entire system via GPS time stamps. Such accuracy and coordination will not only clarify the sequence of events in outage postmortems, but will also open up the possibility for real-time stability analysis, increased situational awareness for control operators, and eventually, automated corrective actions.

In the near term, PMU data will allow operators to rely less on complicated stability models and calculated estimates of the state of the power system. As a result, they can safely reduce operating margins, making grid operation more efficient.

As EPRI senior vice president Arshad Mansoor observed, "The difference between conventional monitoring data and synchrophasors is like that between X-rays and MRIs: with synchrophasors you get an extremely detailed, real-time view of grid dynamics as they occur, rather than a snapshot that must be developed and studied in retrospect. The new technology will make a tremendous difference in managing tomorrow's electricity grid economically and with high reliability."

A Must-Have for Renewables

Having a comprehensive, integrated view of grid dynamics will be especially important as the nation's power system moves from the current hub-and-spoke model to the more matrixed form of the smart grid, with distributed generation and storage units, more renewable power, and substantial new customer loads, such as electric car chargers.

Photovoltaic (PV) and wind generation pose particular problems because of the variability and uncertainty of their intermittent dispatch. And because of the specialized power-electronic controls currently used in their grid interface, many wind and PV generators do not have inherent inertial response, which can impact the dynamic performance of the power system in responding to disturbances. As a result, when large blocks of these new technologies replace conventional generation, the frequency response and modal behavior of the power system will change, requiring more of the close, real-time scrutiny that synchrophasors provide.

In this and many other ways, PMU measurements offer a capability that will be invaluable in the future—coordinated wide-area control that allows local protection devices to be activated in a centralized manner, in some cases automatically and without operator intervention. EPRI is currently forming a team of industry experts to accelerate the development and deployment of such advanced control room applications.

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EPRI Moves to Field Demonstration for the Solid-State Distribution Transformer

Distribution transformers are ubiquitous in the distribution system. Based on a technology developed over 100 years ago, they are extremely reliable in performing their primary function—reducing the electricity supply voltage to a level that can be used safely by customers. EPRI has developed a prototype for an "intelligent universal transformer" (IUT) that applies solid-state technology for voltage conversion and provides additional functionality expected to offer distinct advantages in a more complex delivery system, benefitting consumers and utilities.

Solid-state technology can improve consumer power quality, provide continuous voltage regulation and reactive power compensation, and facilitate distribution automation. Combined with communications technology, the solid-state transformer becomes a smart node within the smart grid that can help detect metering problems, track asset loading, and serve as a data source for real-time condition monitoring and load modeling. It will also help integrate distributed resources such as energy storage, photovoltaics, and plug-in electric vehicles.

Clear Advantages

The IUT converts alternating current (ac) power at various distribution-level voltages to direct current (dc) and ac power ready for residential and commercial use. Unlike conventional copper-and-iron transformers, its solid-state high-frequency switching and fast-computing digital control technologies allow it to control and shape its output characteristics.

It can provide continuous, accurate control of the voltage levels at every customer location. Because it can regulate the customer-side voltage independently of the distribution voltage through active filtering and line voltage regulation, the IUT will improve ride-through capability for voltage sags and mitigate other power quality phenomena. When combined with energy storage that is connected to the dc tab, it can act as an uninterruptible power supply. Customer voltage control is also becoming increasingly important for utilities as an energy conservation and demand management technique.

For future smart grid applications, the IUT can be used to connect distributed renewable generation to the distribution system without the significant distribution voltage variations allowed by conventional transformers. Combining the power electronics required for electric vehicle (EV) charging with the distribution transformer is another promising application.

Unlike conventional units, the IUT retains its efficiency regardless of load—a characteristic that becomes more important with the addition of local generation, which reduces the overall load on the transformer. Other beneficial characteristics include:

- The IUT has no liquid dielectrics, eliminating spill risks.
- The solid-state transformer has the capability to convert a single-phase input to a three-phase output, which can be important in some rural areas.
- Solid-state transformers can be built from modules combined to achieve various transformer ratings for kilvolt-amperes (kVA) as well as voltage.

But some challenges remain, including matching the life expectancy and cost of traditional transformers.

This 2.4-kV IUT prototype was tested in EPRI laboratories in 2011.

Prototype Development

EPRI is leading the development and demonstration of a fully integrated, production-grade 4-kV- and 15-kV-class solid-state transformer for integrating energy storage technologies and EV fast charging. The development team includes utilities, power electronics experts, and a transformer manufacturer to provide guidance on taking the technologies from concept to production.

EPRI has been working on the IUT's solid-state technology for a number of years and has completed proof of concept and various prototype designs that are ready to be included in field demonstrations and early deployment, leading to commercialization of the technology.

EPRI successfully demonstrated a working IUT in December 2010 at its laboratory in Knoxville, Tennessee, and a field prototype 2.4-kV, 25-kVA model with enclosure, packaging, and high- and low-voltage bushings was deployed earlier this year for evaluation. A fully functional EV fast-charger system was evaluated, along with a variety of communication and performance features. A number of field demonstration projects at multiple host sites are scheduled through 2012 to finalize IUT design, specifications, and manufacturing requirements.

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