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ENERGY

Electricity Delivery
& Energy Reliability

American Recovery and
Reinvestment Act of 2009

Synchrophasor Technologies and their Deployment in the Recovery Act Smart Grid Programs

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SMARTGRID.GOV
RECOVERY ACT SMART GRID PROGRAMS

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1. Introduction

The American Recovery and Reinvestment Act (Recovery Act) of 2009 provided $4.5 billion for the Smart Grid Investment Grant (SGIG), Smart Grid Demonstration Program (SGDP), and other U.S. Department of Energy (DOE) smart grid programs. These programs provided grants to the electric utility industry to deploy smart grid technologies to modernize the nation's electric grid. As a part of these programs, independent system operators (ISOs), regional transmission organizations (RTOs), and electric utilities installed synchrophasor and supporting technologies and systems in their electric power transmission systems.

This report has two purposes: (1) to describe, for the non-specialist, synchrophasor technologies, systems, and related software applications; and (2) to describe basic aspects of the Recovery Act-funded projects that are deploying synchrophasor technologies and systems. The report was prepared for DOE by Oak Ridge National Laboratory (ORNL).[1]

2. Synchrophasor Technologies

Synchrophasor technologies and systems use monitoring devices called phasor measurement units (PMUs) that measure the instantaneous voltage, current, and frequency at specific locations in an electric power transmission system (or grid).[2] The sampling of these parameters takes place 20 or more times per electrical cycle[3] which is 1200 or more times per second. PMUs convert the measured parameters into phasor values, typically 30 or more values per second. The PMUs also add a precise time stamp (using a well-defined format known as IEEE C37.118)[4] to these phasor values turning them into synchrophasors. The time-stamping allows

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[2] The electrical transmission system provides the pathway via high voltage and power lines for supplying electricity produced by central generation plants such as nuclear, coal, or hydroelectric power stations to serve end-users. If the end-users are large industrial facilities they might be directly connected to the transmission system. If they are smaller end-users like residential homes then the electricity would be supplied from the transmission to a lower voltage distribution system.

[3] The U.S. electrical power grid operates at 60Hz or 60 cycles per second; thus a cycle is equal to 16.67 milliseconds (0.01667th of a second).

[4] http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=06111219.

Synchrophasors: A Primer

Monitoring devices called phasor measurement units (PMUs) measure the instantaneous voltage, current, and frequency at specific locations in an electricity transmission system (usually at transmission substations, as seen in Figure 1). These parameters represent the “heart-beat” and health of the power system. Voltage and current are parameters characterizing the delivery of electric power from generation plants to end-user loads, while frequency is the key indicator of the balance between electric load and generation. Thus frequency that doesn’t deviate very much from 60Hz is key to ensuring the proper operation of the power system and its reliability.

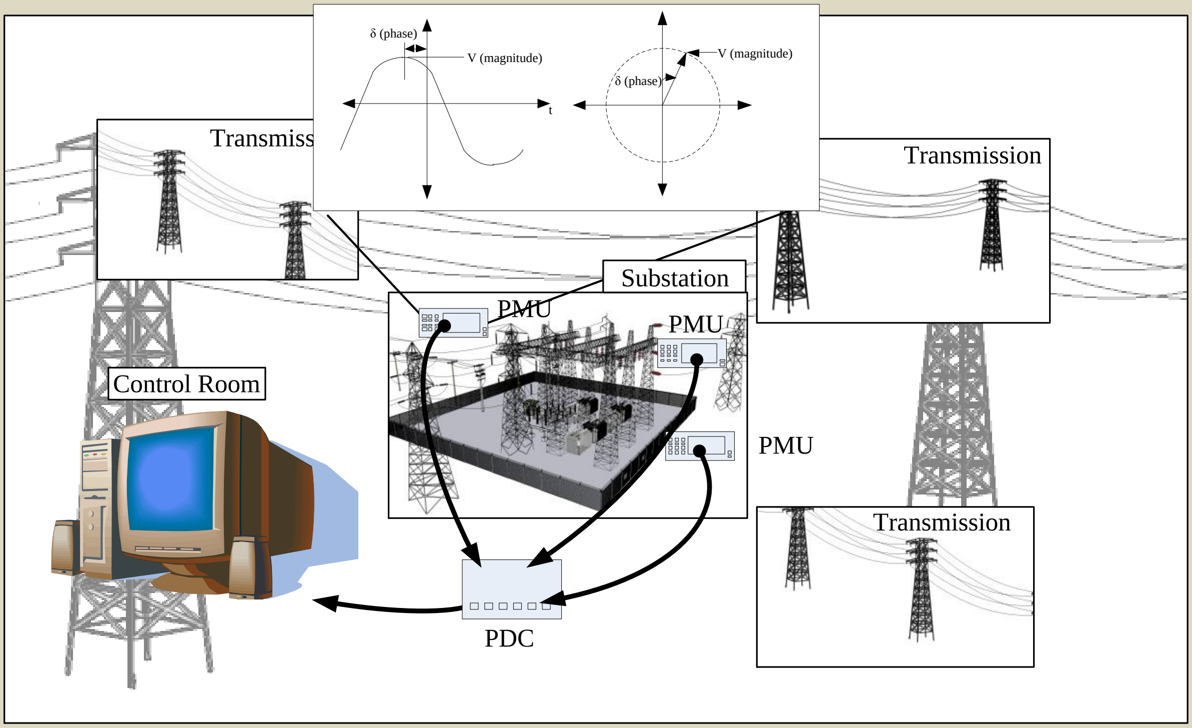

Figure 1. Collection and flow of synchrophasor data

PMUs typically sample grid conditions at a rate of several hundred times per second and use this sampled data to calculate phasor values for electric voltage and current, at a rate of 30 or more per second – compared to conventional monitoring technologies that report once every two to six seconds. A phasor is a complex number that represents the magnitude and phase angle of the sinusoidal waveforms of voltage or current at a specific point in time. The “cutout” at the top of Figure 1 depicts the magnitude and phase angle in the waveform (the left graph) and in vector form (the right graph). Each phasor value is time-stamped, based on the Global Positioning System (GPS) time. When a phasor measurement is time-stamped, it is called a “synchrophasor.” (This term is sometimes used synonymously to refer to a PMU.)

As shown in Figure 1, the synchrophasor data streams of 30 or more a second from PMUs are sent through a communications network to phasor data concentrators (PDCs), which collect, time-align and quality-check the data before sending them on for use in advanced applications software.

Time-stamping allows measurements taken by PMUs in different locations and by different transmission operators to be correlated and time-aligned, and then combined accurately. Such data can provide a comprehensive picture of transmission system operations across an entire transmission region or interconnection.

these phasor values, which are provided by PMUs in different locations and across different power industry organizations, to be correlated and time-aligned and then combined. The resulting product enables transmission grid planners and operators to have a high-resolution "picture" of conditions throughout the grid.

Synchrophasor use has been increasing since 2004[5] when the U.S.-Canada blackout investigation report recognized that many of North America's major blackouts have been caused by inadequate situational awareness for grid operators, and recommended the use of synchrophasor technologies to provide this real-time wide-area grid visibility.[6]

More recently, the North American Electric Reliability Corporation's (NERC's) 2008 Real-Time Tools Best Practices Task Force recommended that real-time operational tools should have high-speed capabilities, both in terms of accessing data and processing the data, to ensure that the electric power systems in the future will be reliable.

The basic components of synchrophasor technologies are: [7]

- PMUs, which calculate and time stamp phasors, and use the created synchrophasors to measure grid conditions. Other devices with PMU-like capabilities include upgraded relays and digital fault recorders (DFRs), which normally capture data during specific events such as system faults (or short-circuits such as when a tree falls against a transmission line), equipment failure, and generators tripping out of service.
- Phasor Data Concentrators (PDCs), which are computers with software that receive data streams from PMUs and other PDCs, time-align synchrophasor data from multiple sources to create a system-wide set of linked measurements that are sent to computers for processing in applications software. PDCs also perform data-quality checks, monitor the performance of the PMUs and feed a data archive. Increasingly, PDC functionality can be located within the grid at transmission substations, aggregating local PMU data

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[5] Original use of PMUs began in parts of both the western (such as Bonneville Power Administration and Western Area Power Administration) and eastern interconnections (such as New York Independent System Operator) in pilot projects during the 1990s.

[6] U.S.-Canada Power System Outage Task Force, *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations*, Washington, DC and Ottawa, Ontario: U.S. Department of Energy and Natural Resources Canada, April, 2004. Available at https://reports.energy.gov/BlackoutFinal-Web.pdf.

[7] The report, *Real-Time Application of Synchrophasors for Improving Reliability*, North American Electric Reliability Corporation, Princeton, NJ, October 18, 2010 (http://www.nerc.com/docs/oc/rapirtf/RAPIR%20final%20101710.pdf) provides more in-depth description and discussion of synchrophasor technologies.

and feeding it to local applications and actions, as well as passing the data upstream to multiple applications and operations centers.

- Communications networks of varying technologies and speeds are used to deliver synchrophasor data between PMUs, PDCs, and operations centers.
- Applications that use synchrophasor data for online and offline use. An example of an online application is real-time grid monitoring and control for use by reliability engineers and by operators in the operations center. Off-line applications include uses such as operations modeling, transmission planning and forensic analysis.

Most of the Recovery Act synchrophasor projects are developing Wide-Area Measurement Systems (WAMS) to collect synchrophasor measurements from PMUs that are on their power system or across the interconnection if they are a reliability coordinator. While transmission operators (TOs) are installing the PMUs, the real challenge is to build interconnection-wide *networks* of PMUs that share information across utilities and regional transmission organizations. DOE anticipates that once all of the Recovery Act synchrophasor projects have been completed, there will be at least 1,043 networked PMUs in place (compared to 166 in 2010), providing significantly greater coverage of the U.S. bulk power system.

3. Advanced Applications Software and their Benefits

Recovery Act projects are developing and/or purchasing advanced applications software to analyze and display synchrophasor data. Most of these applications focus on providing the following capabilities:

- Improved power system monitoring and visualization to aid power system operators' situational awareness and help them forestall grid collapse through better recognition and response to evolving grid events,
- Validation and derivation of system parameters used in power-system models and analytical tools to design and operate a more reliable grid,
- Enhance grid throughput and utilization of existing grid assets,
- Faster and improved forensic analysis following a disturbance that impacts the power system, especially one that results in a blackout.

Advanced applications software providing these capabilities are necessary to realize the full potential of synchrophasor technologies. They will improve grid reliability, power quality, asset utilization and efficiency in grid planning and operations. These are the ultimate benefits of synchrophasor technologies.

Specific categories of advanced applications are discussed below. There are two broad categories: (1) on-line applications which may potentially be used in real-time, i.e., in operations; and (2) off-line applications which are not used in operations but rather to analyze events and blackouts, after the fact, and to validate and improve models.

3.1 Online (Near Real-Time Applications)

Wide-Area Monitoring and Visualization (WAMV)

Several Recovery Act projects are deploying synchrophasor data-based WAMV systems. These systems collect phasor data across an area as wide as an entire interconnection, which could be 100s of miles in size, in real-time and display it for operators to understand grid conditions. Digital displays provide alerts to indicate possible levels of stress in the grid such as areas of low voltage, frequency oscillations, or rapidly changing phase angles between two locations (such as substations) on the grid. Many WAMV applications have diagnostic capabilities that can identify grid stress (measured by the changing phase angles of synchrophasors at different substation locations, termed phase-angle separation), grid robustness in terms of system events (oscillations, damping and trends), instability (frequency and voltage instability), or reliability margin (which describes how close the system is to the edge of its stability boundary). These systems provide context-appropriate graphics and visualizations, basic data archiving, the ability to drill-down into specific locations or conditions on the grid (e.g., voltage or a frequency oscillation), and playback capabilities.

Oscillation Detection

Oscillations occur when a disturbance, such as a generator trips in the power grid and voltage or frequency swing high and low so that they are beyond their standard acceptable operating limits. A stable, well-damped electric system will settle back to normal operating values after an event or disturbance; undamped oscillations causing an unstable system could accelerate and lead to a voltage collapse or blackout. Because PMUs sample grid conditions at very high speeds, they can detect oscillations and facilitate operator alerting or automated intervention to facilitate damping actions, Routine low-frequency (small-magnitude) oscillations occur when an individual or group of generators oscillate or swing against other generators operating synchronously on the same system. These oscillations can be caused by power transfers from one utility system to another when high-speed automatic turbine controls attempt to maintain an exact frequency.

Frequency Stability Monitoring

PMUs measure power system frequency, which is a key indicator of the balance between generation and load in the power system. North America’s ac (alternating current) power system operates at a frequency of 60Hz (60 cycles per second), and normally deviates slightly higher or lower from 60Hz as the state of the power system continuously changes with generation and load. If the frequency is high then the generation is greater than the load, while generation lower than load yields frequency lower than 60 Hz. Abrupt changes in frequency due to major losses in generation or load can compromise power system stability and lead to a blackout.

Voltage Stability Monitoring

Synchrophasor systems can be used to monitor, predict, and manage the voltage on the transmission system of the power grid. One of the most promising near-term synchrophasor applications, which some Recovery Act projects are using, is for trending system voltages at key load centers and at bulk transmission substations. Many transmission systems are voltage stability-limited, which means that the voltage cannot exceed a certain level without causing system stability problems (instead of thermally-limited, when transmission-line conductors heat up as they carry more power flow and fail if they carry too much power for too long). Voltage collapse can happen very quickly if these voltage stability limits are reached or exceeded.

Disturbance Detection and Alarming Studies

Analyses indicate that the rate of change of the phase angle difference between transmission substations, for example, is an important indicator of growing power-system stress. Increasing phase angle or large phase angle difference is used as a basis for transmission operator alarms. One application for synchrophasor-based situational awareness and trending tools is to have them show the trend in phase angles compared to phase angle limits in order to warn operators when the stress is increasing. Such a tool offers intelligence to the power system operator. When phase angles exceed critical limits, operators can perform corrective actions.

Resource Integration

Synchrophasors are expected to be particularly useful for improved monitoring, managing, and integrating of distributed generation and renewable energy into the bulk power transmission system. One of the challenges in integrating these resources is how to identify and respond to their power generation variability. In a conventional system, frequency is controlled by large central rotating generators. However, as more renewables come online, they challenge the ability of the power system to control (or govern) the system frequency because, with renewables, it can change much faster than in a conventional power system without renewables. This variability alters the frequency behavior of the interconnected system and could adversely impact the grid's stability performance. Real-time monitoring of frequency behavior enables operators to take appropriate actions to maintain stability.

State Estimation

Measurements taken on the power system are not always accurate or available due to communications or instrumentation issues such as communication delays or outages. The method of state estimation was developed in the 1970s to address this limitation. State estimators use a model of the power system, measurements, and a least-squares statistical method to mathematically solve for the power system states at the various substations, generators and other instrumented locations on the transmission system. State estimation provides a means of estimating the accuracy of power system measurements and of filling in missing measurements. Synchrophasors can be integrated into state estimators to provide improvements in the power system state calculations. For example, a state estimator can use derived data estimates from a PMU, not currently provided by conventional instrumentation, such as phase angle information.

Transmission Pathway and Congestion Management

Synchrophasors can be used to monitor transmission line loadings and to recalculate line ratings (i.e. the maximum power flow that the transmission line can carry) in real-time. The ability to calculate transmission line ratings based on environmental conditions is called dynamic rating. Without synchrophasors, seasonal summer or winter ratings of lines are typically set based on fixed assumptions regarding ambient temperature, wind speed, and solar heating input to arrive at a conservative figure for transmission line conductor ampacity (flow capacity) based on a maximum allowable conductor temperature. But real-time phasor data for transmission lines can be used in combination with local weather conditions to calculate the actual ampacity of a transmission line, which could be significantly greater than a conservative seasonal rating. Such dynamic line ratings can be used to enhance throughput from facilities that constrain generator output or that constrain service into load centers. Dynamic line ratings can also relieve congestion and reduce congestion costs along key transmission lines, as well as monitor transmission lines that serve variable renewable generation.

Islanding and Restoration

System frequency is an indicator of power system integrity (“health”). Bus frequencies such as at substations are reliable indicators of power system islands and system separation points. Frequency information is also very important during black-start conditions (when the power system has to be completely restarted back up from zero generation and load) and in system restoration following power system break-ups; operators can use synchrophasor data to bring equipment and load back into service without risking power instability or without experiencing unsuccessful reclosing attempts that prolong outages.

3.2 Offline (Not real-time) Applications

Post-Event Analysis

Post-event analysis is necessary to ensure that lessons are learned to correct problems that previously led to an event, to train system operators on the lessons learned, and finally to take measures to correct the problem. None of these measures are possible until a post-event analysis is completed. Synchronized wide-area data via synchrophasors is essential for post-event analysis of power systems. Data synchronization is critical for the sequence of event reconstruction, particularly for complex events where the switching of many devices in the system occurred in a short-time frame. Prior to synchrophasors, it could take many months of investigation to reconstruct the sequence of events that caused a blackout. However, having a synchrophasor-based WAMS in place greatly reduces the time required to complete a post-event analysis to days or hours.

Model Validation

Planners and operators are using synchrophasor data to improve power system models, whether they are steady-state (in which only small changes occur in the power system during long time periods such as 1 second to minutes) or dynamic (with relatively large changes occurring in the power system during a short time period such as less than 1 second). The high-speed synchrophasor observations (30 or higher times per second) of power system grid conditions allow modelers to calibrate models to better understand system operations, to identify errors in system modeling data or in model algorithms or simulations, and to fine-tune the models for on-line and off-line simulation applications. Synchrophasors are also being utilized to track dynamic parameters so that models can be adjusted over time to accurately reflect gradual changes in generator parameters or time-sensitive parameters such as transmission line conductor impedance and grid topology.

4. Recovery Act Synchrophasor Projects

Under the Recovery Act SGIG and SGDP programs, twelve grant recipients are spending about $400 million, including their cost-share (which is at least a 50% match), to deploy synchrophasor technologies.[8] These technologies include PMUs and other high-speed data collection devices (such as upgradable relays, and upgradable dynamic fault recorders); PDCs;

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[8] The $400 million figure includes an estimate of the portions spent on synchrophasor technologies by projects that also installed other smart grid technologies such as advanced metering infrastructure and distribution automation.

and communications systems; as well as advanced applications software that use synchrophasor data to improve planning and operation of electric power systems.

Table 1 lists the grant recipients and the number of PMUs and PDCs which each has installed thus far. The table lists both the numbers installed as part of the Recovery Act project, and the overall totals installed in the grant recipients' service areas, including those installed prior to and during the Recovery Act project. Although several grant recipients had already started deploying PMUs and PDCs prior to their receiving the grants, the Recovery Act programs clearly had a major impetus on the build-out of this technology. Some grant recipients would have had no PMUs or PDCs installed in their transmission systems at all had they not received a Recovery Act grant.

SGIG and SGDP Synchrophasor Project	PMUs Installed*		PDCs Installed*	
	Recovery Act Project^	System Total	Recovery Act Project^	System Total
American Transmission Company	45	92	0	2
Center for Commercialization of Electric Technologies	15	18	4	4
Duke Energy Carolinas	98	98	2	2
Entergy Services Inc.	49	49	9	10
Florida Power & Light Company	45	45	13	13
Idaho Power Company	8	15	0	1
ISO-New England	77	77	8	8
Midwest Energy	7	7	1	1
Midwest Independent Transmission System Operator	148	148	21	21
New York Independent System Operator, Inc.	40	40	8	8
PJM Interconnection	56	56	15	15
Western Electricity Coordinating Council	336	481	49	69
TOTAL	924	1126	130	154

** As of 03/31/2013*

^ "Recovery Act Project" includes those installed with matching funds.

Table 1. Numbers of PMUs and PDCs Installed in Recovery Act-Funded Projects

Source: Calculated by authors from data reported to DOE by Recovery Act-funded projects.

The synchrophasor systems being deployed by the grantees will increase the current synchrophasor coverage of transmission systems ten-fold. Figure 2 is a map showing the service areas of each of the twelve recipients. The map illustrates that the Recovery Act projects cover large portions of the country. Although the projects will not necessarily achieve 100% coverage of every recipient's service area, for most recipients, major portions of their area will be covered by the PMUs.

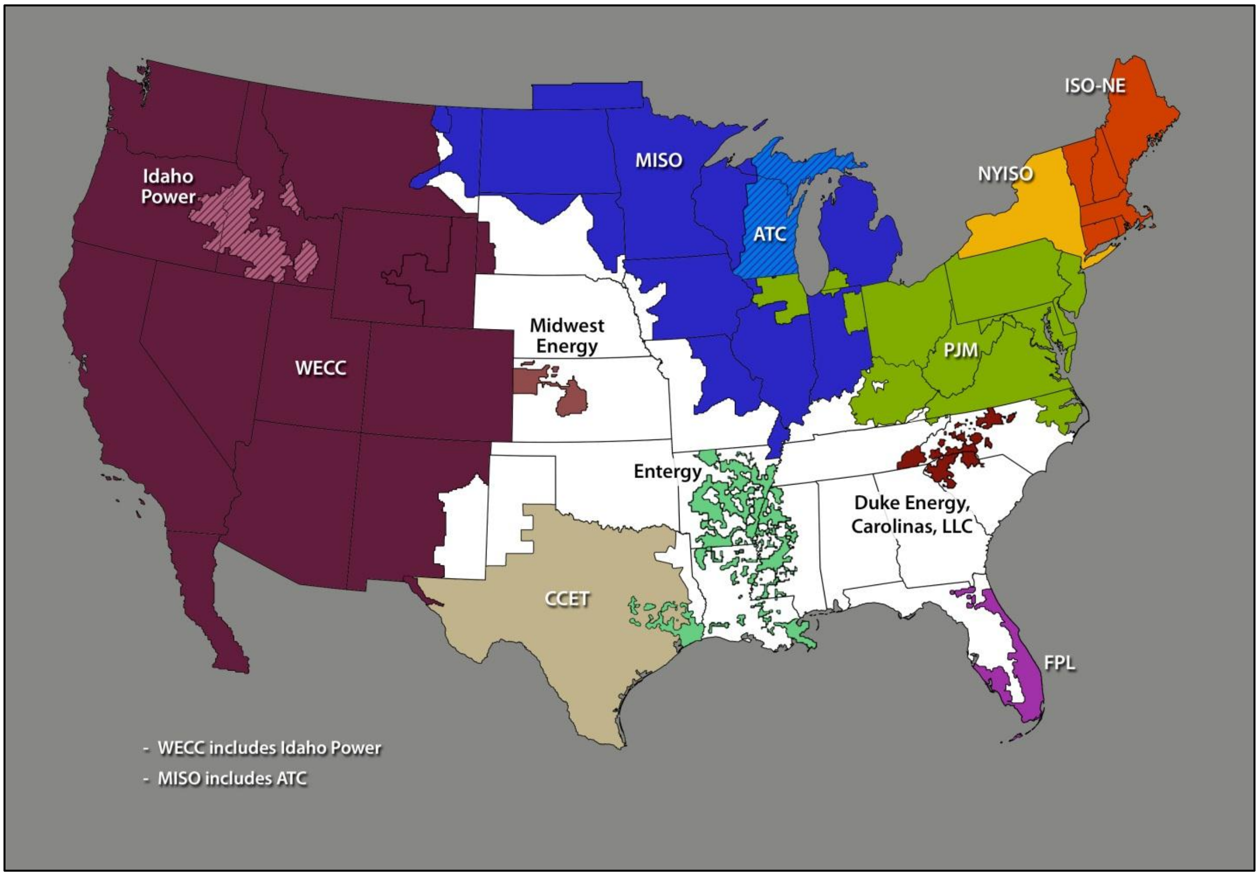

Figure 2. Service areas of RECOVERY ACT synchrophasor-project grant recipients

Sources: Platts 2013 Maps & Geospatial Software by McGraw-Hill Financial[9]*, Electric Reliability Council of Texas (ERCOT) coverage area*[10]*, Entergy service area in Texas*[11] *and American Transmission Company (ATC) service area*[12]*.*

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[9] http://www.platts.com/maps-geospatial

[10] http://www.ercot.com/news/press_releases/show/84

[11] http://www.entergy-texas.com/about_entergy/counties.aspx

[12] http://www.atcllc.com/about-us/service-area/attachment/atcserviceterritory2010/ and http://www.atcllc.com/wp-content/uploads/2011/05/ATCTerritory34x34April2011_000.pdf

In terms of the advanced applications discussed in Section 2, some RECOVERY ACT projects plan to focus on one or a few of the applications; other projects plan to implement most of them. As of March 2013, one or more projects are using the following applications (though not in real-time operations yet):

- Wide-area monitoring and visualization
- Voltage stability monitoring
- Islanding and restoration
- Post-event analysis
- Model validation

5. Costs and Benefits of Synchrophasor Technologies and Systems

This section provides initial information about the costs and benefits of the synchrophasor technologies and systems based on data from the SGIG and SGDP synchrophasor projects. This information will be updated as more information from the projects becomes available.

5.1 Costs: the Experience of the Recovery Act Synchrophasor Projects

Table 2 summarizes the cost data provided thus far for the Recovery Act synchrophasor technology deployments. These reported costs are the total *installed* cost of the technology which includes the cost of the device or system itself; design and engineering costs; labor and materials costs for installation, as well as any needed construction; and overhead. These cost data are preliminary in that, for example, some projects have many partners and some had not yet reported all of the cost-share amounts they had contributed.

Technology	Median of Projects' Average Costs
Phasor Measurement Units (PMUs)	$43,400/PMU
Phasor Data Concentrators (PDCs)	$107,000/PDC

Table 2. Costs of Deploying Synchrophasor Technologies

Source: Calculated by authors from data reported to DOE by Recovery Act-supported projects.

The median costs listed in the table for PMUs, or PMU-like devices, and PDCs are the median of the average PMU or PDC cost within each project. As previously noted, the reported costs include installation and any other costs which the grant recipient allocated to the PMU or PDC cost category. Based on informal discussions with vendors, the cost of the equipment itself could be only one-quarter of the total reported installed cost – and this fraction varies depending on the vendor, equipment and the complexity of the project.

The average installed cost of PMUs and PDCs varies considerably across projects. In some projects, the average cost per PMU or PDC installed is more than double the median value among projects; in other projects, it is less than half the median value. These devices can have different functional specifications and capabilities, and thus cost. Some projects upgraded existing equipment such as digital fault recorders to give them PMU functionality; such upgrades cost considerably less than installing new PMUs. Projects also faced different construction requirements in installing the devices. There did not appear to be any economies of scale, however; projects installing a greater number of PMUs or PDCs did not have lower average costs per device.

An additional reason for the variation is that, for many grant recipients, these technology deployments were projects where the recipients had limited experience. The projects were more about research, design, demonstration, testing and learning about the technologies – all of which incurred costs – than straightforward installation of devices. The PMU and PDC cost categories were defined so as to include such design, overhead and other costs; and each recipient allocated them differently to the PMU and PDC cost categories, or to other cost categories. One would expect that future installations will be less costly, on a per PMU and PDC basis, than those reported in the Recovery Act synchrophasor projects.

Given the variation among projects and accounting for the considerations and caveats discussed above, the median values in Table 2 are mid-range estimates of the total PMU and PDC costs incurred by the projects. These reported costs include not only the cost of the PMUs or PDCs themselves, but also the design and engineering, installation, settings, commissioning, and any other costs allocated to the installation of the synchrophasor technologies.

In terms of other equipment needed for synchrophasor systems, other than the PMUs and PDCs, the greatest amounts spent by any one project thus far were $710,000 on advanced applications, $15,000,000 on communications systems, and $4,800,000 on back office systems. However, the costs vary considerably across projects because they had different needs and priorities. Also, the utilities and projects were of different sizes. In addition, some utilities used the Recovery Act funding for major expansion or upgrade, whereas others only made incremental improvements to their existing systems. Some projects did not need to use Recovery Act funds to upgrade these components at all.

5.2 Benefits of Synchrophasor Technologies and Systems

To make any business case for investing in synchrophasor technologies, one must evaluate its benefits. The most important benefits of synchrophasor technologies include:

- *Reliability improvements* in the bulk transmission system (reduced frequency, duration and extent of outages, and their impacts on customers; and faster restoration of outages and reduced cost to utilities), e.g., through enhanced situational awareness and advanced applications; for example, advanced software using synchrophasor data can provide early, improved detection of evolving grid problems and provide operators with the ability to take mitigation measures;
- *Economic improvements* (including reduced operations and maintenance costs; reduced energy and ancillary services costs; cost savings from improved asset utilization and operational efficiency; and reduced costs to customers); for example, synchrophasor technologies can provide more precise determination of system limits, such as higher resolution of voltages, currents and frequency – enabling operations to be closer to those limits; and
- *Enhanced integration and operation of distributed energy resources* (renewable and nonrenewable generation and energy storage); for example, synchrophasor data can be used to improve monitoring of grid system behavior that can be affected by generation using renewable energy sources.

For synchrophasor technologies to gain broader acceptance and use, these benefits need to be documented from the actual experience of their use and operation. One of DOE's objectives in its Recovery Act-funded programs is to document the impacts and benefits – and thus the value proposition – of different types of smart grid technologies – including those described in this article.

Given the many potential factors that might affect grid reliability and operations, it is challenging to estimate with precision a quantitative benefit resulting from the technology. One of these challenges lies in quantitatively defining the counterfactual condition (i.e., the costs, outages, or resource integration that would have occurred if no synchrophasor technologies had been installed). In addition, events that might clearly demonstrate the capacity of synchrophasor technologies to improve power system resilience are rare, such as black-outs in the bulk transmission system. They are also often the result of natural disasters and might reflect confounding factors that are difficult to statistically control in any analysis to estimate the impact of the technologies. Notwithstanding this challenge, one of DOE’s goals in its SGIG and SGDP programs is to report, over the next couple of years, on the experience of the projects regarding the performance and value of the synchrophasor technologies they have installed.

6. Summary and Final Thoughts

The U.S. Department of Energy provided Recovery Act funding to twelve recipients to expand the nation’s synchrophasor infrastructure. According to NERC, these technologies are needed to meet the technology requirements for real-time tools so as to ensure the continued high reliability of the nation’s electric power system. Synchrophasor technologies establish the foundation needed to operate and control the *future* power grid as it becomes more complex with increasing reliance on renewable energy generation, continued growth in electric transmission, and greater diversity of end-use electrical loads such as sophisticated power electronics. With the stimulus of the SGIG and SGDP projects in place, it is now up to the power industry, with the support of its regulators, to build out this networked infrastructure to ensure that the reliability of power systems is maintained well into the future.

Having a network of PMUs in place is one thing, but actually using the synchrophasor data that it produces is another. Utilities, ISOs and RTOs have each established their own planning and operating procedures. Synchrophasors, being relatively new technologies, are currently not part of these procedures and it will take a while for them be become mainstream. DOE hopes that, by 2015, 50% of TOs will have, to some degree, planning or operating procedures in place that incorporate synchrophasor measurements.

A key catalyst to spur the adoption of synchrophasor technologies for mainstream use is to demonstrate their value proposition. As the projects progress, there will be further evidence of the benefits and costs of synchrophasor technologies. One of DOE’s priorities over the next few years will be to document and communicate this experience so as to provide a broader understanding of the benefits as well as the limitations and costs of these technologies. DOE’s smartgrid.gov web site will continue to report on the build-out of these technologies and DOE plans to issue reports in the future on their costs, impacts and benefits.

Appendix. Acronyms and Abbreviations

ATC – American Transmission Company

CCET – Center for Commercialization of Electric Technologies

DFR – Digital Fault Recorder

DOE – Department of Energy

ERCOT – Electric Reliability Council of Texas

FPL – Florida Power & Light Company

GPS – global positioning satellite

Hz – hertz such as the U.S. electric power system operates at 60Hz or 60 cycles per second

IEEE – Institute of Electrical and Electronic Engineers

ISO – independent system operators (ISOs)

ISO-NE – ISO New England

MISO – Midwest Independent Transmission System Operator

NERC – North American Electric Reliability Corporation

NYISO – New York Independent System Operator

OE – DOE's Office of Electricity Delivery and Energy Reliability

PDC – Phasor Data Concentrator

PMU – Phasor Measurement Unit

RTO – regional transmission organization

SCADA – supervisory control and data acquisition

SGIG – Smart Grid Investment Grant

SGDP – Smart Grid Demonstration Program

TO – Transmission Operator

WAMS – Wide Area Measurement System

WAMV – Wide Area Monitoring and Visualization

WECC – Western Electricity Coordinating Council