The Office of Electricity Delivery and Energy Reliability of the U.S. Department of Energy (DOE), the Bonneville Power Administration (BPA), and industry and academic collaborators have leveraged resources to develop a new, cost-effective method for validating power plant models using synchrophasor data.

Power plant models are key components of power grid models, which are used by the power industry as planning and operating tools (see Figure 1). Validating power plant models therefore improves the overall power grid models. Power grid models are used to simulate the effects of different events and scenarios on the power grid to assess overall system performance and reliability. For instance, models of the power grid are used to determine the best course of action to mitigate the reliability impacts of a disturbance in the event that a power plant suddenly drops off-line or a transmission line opens because of a lightning strike.

Power plant models are established from data obtained from staged testing, in which engineers run certain tests on generators to determine the values of parameters that mathematically characterize the behavior of the power plant. These values are then used in the creation of a model of the power plant tested. These models can give an accurate representation of the behavior of power plants as they interact with the transmission grid. But the values originally used may change...
Using Synchrophasor Data to Validate Power Plant Models

as conditions in the power plant change—when equipment is upgraded, for example. The importance of keeping models current is reflected in the policy of the Western Electricity Coordinating Council (WECC) and several other grid-operating entities, which require power plant model revalidation every five years or when changes are made to relevant plant equipment.

The revalidation of the power plant models can be achieved by repeating the staged tests that are the basis of the initial model construction, but this is expensive due to lost revenue, fuel requirements, and other costs. It also does not provide a complete picture, as staged tests cannot capture the response of the generator to unplanned disturbances on the power grid. The increasing use of phasor measurement units (PMUs) and synchrophasor data has enabled operators to analyze the response of generators to such disturbances, which in turn has begun to improve power plant models and can pave the way for validation models using PMUs to supplement and potentially defer certain staged tests. Power plant model validation techniques developed with funding from the DOE and the BPA could ultimately reduce outages, increase reliability, and reduce the costs associated with power plant model validation testing.

Limitations of Today’s Models

Power plant modeling accuracy became a concern in 1996, when the Western Interconnection experienced several major power system outages. System engineers at the Western Systems Coordinating Council (WSCC, now the WECC) attempted to reproduce these events using their existing power grid simulation software, but they found
significant differences between the simulations and the actual data recorded during the disturbances (see Figure 2). This created concern that the models were unable to predict the reliability impacts of grid disturbances. Because these simulations are used for setting system operating limits, WSCC system engineers were concerned that the interconnected power system could be running above its operating limits, which could create unsafe conditions and ultimately cause major outages. To restore confidence in the models, WSCC instituted a policy that requires regular testing of generators whose capacities are greater than 10 MW to confirm that the parameters used to represent them in dynamic simulations are accurate. Since 2006, WECC’s Generating Unit Model Validation Policy has required power plant model data validation at least once every five years. In 2007, the North American Electric Reliability Corporation (NERC) also began developing standards that would require power plant owners to perform periodic verification of power plant models. While many improvements to power grid models have been made as a result of these validation tests, differences between data in the simulations and measured performance still exist.

Accurately characterizing the performance of power plants for modeling studies necessitates running tests that require the plants to be shut down from normal operation and forego revenues from power sales. Testing may expose problems that must be fixed before returning the power plant back to operation, further reducing revenues. The cost to have a consultant perform model validation tests and submit the models and a test report can range from approximately US$15,000 to US$35,000, depending on the number of generators requiring testing. Other costs include staff time and fuel costs.

In addition, various constraints limit the options when designing staged tests. The practicality and costs of staged testing depend on the type of plant. The options for gas turbine units in urban areas may be limited by air quality requirements so that favored test methods may not be permitted. Even the scheduling of staged tests can be difficult. Testing is generally performed during scheduled maintenance periods, when power prices are low. Many different entities may want to test during the same time period, but there are only a few specialists available to perform generator testing.

Figure 1. Power plants need to be modeled accurately to let grid operators use simulations to assess overall system performance and reliability.
Significant differences existed between (a) the actual disturbance recordings and (b) the simulation at the California-Oregon Intertie (COI).

Finally, staged testing is planned and is generally run while the plant is shut down for normal operation. This has been effective for building power plant models, but it notably does not contain vital information on the response of the power plant to a transmission-level system disturbance.

The BPA Power Plant Model Validation Project

In 1999, the BPA began efforts to develop techniques for validating power plant models using data from PMUs installed at the generators’ points of interconnection, with the goal of supplementing the traditional power plant model validation methods described above. Disturbance recordings could then be compared with simulations, and the power plant models could be adjusted to more accurately predict future responses to disturbances.

The BPA worked with General Electric (GE)—the provider of the power system load flow (PSLF) simulation software used to simulate the power grid in the WECC—to develop capabilities within the PSLF application to play actual disturbance recordings into grid simulations. The BPA applied this capability to several of the hydroelectric generators in the BPA’s service territory (including the Dalles Dam, shown in Figure 3), resulting in significant revisions in the turbine governor models.

In 2003, the BPA worked with TransAlta to extend the work from hydroelectric generators to a large, coal-fired power plant, using disturbance recordings to supplement baseline tests and confirm the validity of the generator models at TransAlta’s Centralia power plant, near Centralia, Washington. The approach greatly minimized the time that the generator was required to be off-line, resulting in significant cost savings for the generator owner.

In 2006, the WECC approved its Generating Unit Model Validation Policy, requiring power plant owners to provide evidence every five years that their models are accurate and up to date. Under certain circumstances, using PMU disturbance data with a PSLF play-in function (as described below) can be an acceptable method for power plant model validation. Having PMU recordings therefore helps BPA customers comply with WECC policy.

The PMU disturbance recordings are used on a regular basis for power plant model verification. When an accurate baseline of a power plant’s behavior is developed, the PMU data can be used to detect control-related abnormalities. In 2009, for example, BPA engineers noticed that the 750-MW Grand Coulee hydropower generators responded very differently to a system oscillation than the expected baseline would have predicted. The generator’s power oscillations persisted, while the expected response was well dampened (see Figure 4). Further examination suggested that the generator’s power system stabilizer (PSS) was not functioning.

In 2009, the Grand Coulee hydropower generator’s response to an oscillation (blue) differed from the expected baseline response (red), helping engineers to determine that the power system stabilizer had failed.
Control inspection by the plant operator confirmed that the plant’s PSS had an internal failure that could only be detected by using disturbance recordings from line PMUs near the generating unit.

To date, the BPA has installed PMUs at 15 power plants that account for approximately 70 generators, totaling more than 18,000 MW of generating capacity. The types of generators being measured include hydroelectric, natural gas, coal, nuclear, and wind.

**The DOE/BPA Generator Model Calibration Project**

Building on these successful efforts, the BPA sought to continue expanding this work for power plant model validation as well as to involve others in the industry in further improving the technique. Through its Technology Innovation program, the BPA announced opportunities for other organizations to work with the BPA on these efforts. A team at the University of Wisconsin-Madison (UW) applied to work with the BPA under a cost-sharing agreement.

The UW team developed analytical methods for calibrating dynamic power plant models using a set of disturbance recordings. The approach proposed by the UW team uses pattern recognition to find relationships between power plant model parameters and the dynamic performance of the power plant, as measured by a PMU. Then an expert engineer can tune the power plant model parameters to obtain the best match between the model and the disturbance recordings. This collaboration strengthened the techniques so that they could be applied to other types of power plants. Following these successes, the BPA made a request to the DOE for additional funding support to begin to prove the concepts and develop a version of the process that could be transferred and used throughout the western United States. The DOE tasked the Consortium for Electric Reliability Technology Solutions (CERTS) to continue the work with UW and the BPA to initiate these enhancements.

Using the newly developed methods and tools developed in conjunction with CERTS, the BPA applied the approach to the Columbia Generating Station (CGS), a 1,150-MW nuclear power plant near Richland, Washington. Initially, the CGS power plant was not accurately modeled, and the model was not able to reproduce the disturbance recordings, as shown in Figure 5(a). Such a mismatch would usually

![figure 5](image)

**figure 5.** (a) The disparity between the responses from two actual disturbance recordings (blue) and the response from the CGS model (red) before the CERTS-developed calibration technique was applied. (b) The same two disturbance recordings (blue), but the CGS model (red) has now been calibrated to more accurately reflect the actual response.

Power plant models are key components of power grid models, which are used by the power industry as planning and operating tools.
The BPA has installed PMUs at 15 power plants that account for approximately 70 generators, totaling more than 18,000 MW of generating capacity.

require generator retesting according to WECC policy. But the BPA engineers, using the CERTS-developed approach, were able to calibrate the CGS model to match the actual responses from several disturbance recordings without taking the generator off-line for retesting. The result is shown in Figure 5(b).

Benefits
As the examples above demonstrate, there are numerous benefits associated with using PMUs to assist in power plant model validation. Monitoring power plants using PMUs lets operators determine whether the simulated response to an unplanned system disturbance matches the actual response data captured by the PMU. This knowledge can then be applied in several ways. First, it can be used to continuously improve the models of power plants using the calibration methods described above. Any improvement in a power plant’s model improves the overall simulation models of the power grid and thus the overall reliability of the power grid. In addition, this information can be used to identify and troubleshoot malfunctioning equipment, as was demonstrated at Grand Coulee.

In certain cases, the WECC will let a generator revalidate its power plant model using synchrophasor data, which could defer the need for a staged test. For example, at the Hermiston power plant, a natural gas–fired combined-cycle cogeneration facility in Hermiston, Oregon, operated by Calpine Corporation, system engineers demonstrated that the PMU data matched the simulations of the response of the plant to system disturbances. Since no major equipment was upgraded, the WECC deemed the plant’s model accurate and approved the revalidation without the need for staged testing. According to Alan Roth, a senior electrical engineer with Calpine Corporation, this allowed the validation tests for both the generator governor and exciter models to be deferred. This saved at least one full day of testing, allowing the plant to continue operation without interruption, which avoided the loss of revenue and costs associated with testing the plant. Even in situations where system tests are deemed necessary, PMU data can help reduce the time the plant is required to be off-line for revalidation. In addition to saving money, this validation method does not require potentially hazardous tests on generators that could damage older equipment, making it a safer, less invasive option.

The BPA’s experience has been that model validation using disturbance recording is often a better, more cost-effective, and safer alternative to staged tests. Overall, this power plant model validation method has the potential to reduce outages, increase reliability, and save money.

Future Work
As PMU-based model validation capabilities continue to improve, the BPA is sharing its success with industry. The BPA, through the WECC, has engaged other organizations in connection with the research, and many entities are now seeking to use this technology to improve their power plant models. Currently, the BPA is in contact with Salt River Project, Southern California Edison, and Pacific Gas and Electric, with the goal being to expand the work across the Western Interconnection.

In 2010, the BPA initiated an effort to expand PMU network coverage to wind power plants. The BPA has experienced a rapid growth of wind generation, from 250 MW in 2005 to 5,000 MW today. This growth has increased the need to consider the effects of wind power plants on the power grid. New PMUs will provide vital data needed for wind power plant dynamic performance assessment and model validation. The BPA is partnering with the Electric Power Research Institute, National Renewable Energy Laboratory, and Utility Variable Generation Integration Group in wind generation model validation efforts.

The American Recovery and Reinvestment Act of 2009 funded nearly a dozen synchrophasor projects totaling over US$200 million, including wide-scale deployment of PMUs. For example, the DOE awarded the WECC US$53.9 million in funding for the Western Interconnection Synchrophasor Program (WiSP). (See http://www.smartgrid.gov/recovery_act/overview/smart_grid_investment_grant_program, under Electric Transmission, for other projects.) The funding matches dollars committed by nine partners in the western United States to extend and deploy synchrophasor technologies within their electrical systems. The BPA is the largest contributor of these nine cost-sharing participants. The total funding for WiSP is US$107.8 million. Ten additional participants are installing PMUs and system infrastructure outside of the DOE grant funding to help achieve full observability of the Western Interconnection. One of WiSP’s deliverables is to use synchrophasor data to improve and verify the accuracy of generator models. These projects, when completed, will supplement and reinforce the achievements and value of the work done by the BPA and the DOE.

As the project continues to succeed and scale up, new technical challenges have emerged for the DOE-CERTS
and BPA team. The partners will need to continue to work together to improve the project, including automating the model validation processes and streamlining data management. Steve Yang, an engineer performing model validation studies at the BPA, describes his vision of the project as follows: “I arrive at work and find an e-mail message from the WISP server about an underfrequency event that occurred earlier. I start the power plant model validation application, and within minutes I get a report on the dynamic performance of the entire BPA generating fleet during the event. I notice that one plant responded differently from what was expected. I pull out a report on that plant’s performance over the past ten disturbances to find out when the response changed, and I run sensitivity analyses of possible controller failures. I e-mail the report to the plant operator, asking to confirm my findings. This helps us resolve any issues at their initial stages, stopping them at the source and keeping them from escalating into costly and time-consuming problems that affect the system’s reliability.”
Other Synchrophasor Projects

The power plant model validation work funded by the BPA and the DOE is one of many synchrophasor projects taking place across the country, and it demonstrates how the DOE can effectively advance a technology while sharing costs with industry. Four example research and development projects that the DOE is cost-sharing are described below:

• Virginia Polytechnic Institute and State University is developing analytic tools and calibration techniques for measurement devices to implement an innovative synchrophasor-based tracking system to monitor the state of the electric grid. The techniques will better diagnose the sources of network unbalances and identify actions needed to remedy them.

• The University of California is developing tools using synchrophasor measurements to reduce the likelihood of false and inappropriate triggers of transmission system circuit breakers that protectively shut down electrical flow and can contribute to cascading blackouts.

• Georgia Tech Research Corporation is developing a tool for electrical system operators to continuously track, in real time, the condition and stability of an electric power system.

• The Electric Power Research Institute is developing a novel synchrophasor-based system that can be installed at control centers to monitor grid conditions and improve grid reliability. The system will be able to perform real-time reliability monitoring, near-real-time event replay, and post-event analysis that will allow operators to better track conditions and thereby take corrective action when needed.

In fact, as the Grand Coulee example above demonstrated, the DOE-CERTS/BPA team is well on its way to realizing this vision. A comprehensive timeline of the project is given in Figure 6. Other projects (see “Other Synchrophasor Projects”) are pursuing similar goals.

Conclusion

By leveraging resources from the DOE, including funding and expertise, and working with a number of collaborators, including GE and CERTS, the BPA has led the creation of a supplemental model validation improvement option that generator operators can use in most scenarios. Using PMUs to continuously record data at generator points of interconnection helps generator and system operators confirm that the power plant model being used in the overall model of the power grid exhibits the same response as the data being recorded. This improves the power grid models, ultimately reducing outages, increasing reliability, and reducing costs.

For Further Reading


Biographies

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