Calibrating the Smart Grid

Application Note

Today's Smart Grid is a dynamic network of electrical supply, demand, and control. That control is made possible by a component known as a Phasor Measurement Unit, or PMU. Until recently, testing processes and equipment were inadequate to ensure the consistent performance of PMUs. Fluke Calibration, under a grant from the National Institute of Standards and Technology (NIST), is developing an automated system to properly test and calibrate PMUs.

What created the need for a PMU calibration system? How does the Fluke system meet those needs? For that, it's best to go to the beginning of the story...

Evolution of the electrical power grid

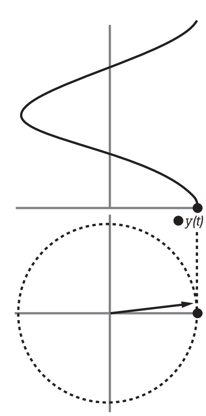
In 1940 the Empire State Building, the Chrysler Building, and the SS Normandie were state of the art. The new Douglas DC-3 was aerodynamically stable and manually controlled with cables. Grand Coulee Dam would come online in 1942, governed by manual and analog controls that could regulate the 60 Hz generators to within a few cycles per day. For voltage or current reporting, time resolution on the order of several seconds was just fine. Electrical power flowed from a few concentrated sources to predictable, load-only customers. Life on the control and reliability front was good!

Today, 3,000 US electrical utility companies operate 10,000 concentrated generation facilities and 200,000 miles of transmission lines. In today's "Smart Grid," traditional, concentrated power sources like hydroelectric dams and coal plants have been joined by distributed, time-variant sources like wind and solar. Customers who once only consumed power now also generate and store power. They can elect to buy power when it is cheap, and even want to sell power back to the grid. New electronic power supplies push distortion back onto the grid. Demand from electric vehicles is ramping up. Today's grid looks less like the DC-3 and more like the fly-by-wire F-16, a high-performance, inherently unstable aircraft that cannot fly without computer assistance.

To maintain the reliability record of the electrical generation, transmission, and distribution utilities, real-time computer control of the grid will be required. Real-time state measurement at widely spaced nodes, with <1 µs time accuracy, is the foundation of this control. That's where the phasor measurement unit, or PMU, comes in.

Phasors, synchrophasors, PMUs, and their applications

A phasor is a rotating "phase vector," an alternative expression of a sine wave.



A phasor can express voltage or current at any point in a power grid. While the word sounds very 21st century, the phasor is a 19th century invention. Charles Proteus Steinmetz, contemporary of Edison, Tesla, and Einstein, first expressed the concept in 1893.

A phasor with a GPS-derived time stamp is called a synchrophasor. Per the North American SynchroPhasor Initiative (NASPI, www.naspi.org):

"Synchrophasors are precise grid measurements now available from monitors called phasor measurement units (PMUs). PMU measurements are taken at high speed (typically 30 observations per second—compared to one every 4 seconds using conventional technology). Each measurement is time-stamped according to a common time reference. Time stamping allows synchrophasors from different utilities to be time-aligned (or "synchronized") and combined together providing a precise and comprehensive view of the entire interconnection. Synchrophasors enable a better indication of grid stress, and can be used to trigger corrective actions to maintain reliability."

Over 2000 PMUs are deployed worldwide, with 1000 of those in China and 500 in North America. This count is growing rapidly due to infrastructure investments. In the US, PMU projects are funded via Smart Grid Investment Grants (SGIG) and the American Recovery and Reinvestment Act (ARRA).

The first applications for Smart Grid synchrophasor data were modeling and analysis. As utilities have become more comfortable with the technology, applications have expanded to fulfill the promise of real-time control and protection. Common applications include:

Interoperability and calibration expense slow PMU deployment

According to Electric Power Research Institute (www.epri.com) Report 1015511:

"The reliable power sources, samplers and associated standards for PMU testing and calibration have become a major hurdle to the further development and implementation of PMU applications in power system. Utilities need the guarantee of reliability and accuracy of PMUs and also the seamless interchangeability among the PMUs from different vendors."

The need for interoperability—consistent and reliable performance across makes and models of PMU—is being addressed by new IEEE standards for test and calibration of PMUs. The performance limits for PMUs are defined in the normative standard IEEE C37.118.1:2012, *Synchrophasor Measurements for Power Systems*, now ratified for January 2012 publication.

Changes in 118.1 include:

- Clarification of the phasor and synchronized phasor definitions
- Expansion of the concept of total vector error
- Addition of tests with temperature variation
- Introduction of dynamic performance tests
- Development of limits and characteristics for frequency measurement and rate of change of frequency (ROCOF) measurement

A PMU integrated with other functions

PMUs are supplied as standalone units or integrated with other functions. An example of the latter is the Schweitzer SEL-421 Protection, Automation, and Control System.

> **"Protect transmission lines with high-speed distance and directional functions. One set of three-phase voltages and two sets of three-phase currents are available for synchrophasor measurement. Send data in SEL Fast Message format or IEEE C37.118 format with up to 60 messages per second."**

Source: www.selinc.com

New standards for testing and calibration of PMUs

In February of 2010, NIST made a grant to Fluke to conduct a requirements survey for a PMU Calibration System and to develop a commercially available Cal System that met those requirements. Here are the benefits that accrue to the calibration community from the NIST grant.

1. **Access to a PMU Simulation Model via NASPI Phasor Tool Repository**
2. **Interoperability across PMUs derived from new standards and procedures**
   - IEEE C37.118:2012 Normative standard updated, published in two parts
   - 118.1–Measurement; static tests revised, dynamic tests added
   - 118.2 - Data Transfer
   - IEEE C37.242 Informative Guideline created
3. **Pathway to worldwide standards adoption**
   - 118.1 to IEC via IEC TC-57
   - 118.2 to IEC 61850
4. **An inter-comparison of PMU measurement performance using the calibration facilities of Fluke, NIST, EPRI, and selected universities**
5. **A commercially-available, automated PMU calibration system**

Analysis	Control	Protection
Wide Area Situational Awareness (WASA)	Real-time wide-area system control	Low frequency oscillation management
Steady-state and dynamic model benchmarking	Generator governor stability control	Early warning and backup protection
Voltage stability monitoring	Synchronization, loop closing assist	Load demand variation (load shedding)
State estimation	Variable/intermittent source integration (e.g. wind and solar)	Adaptive protection
Post-mortem fault analysis	Reserve generation management	Self-healing grids
Phase angle difference stress monitoring	Control of distributed generation system	Adaptive islanding

View PMU success stories on NASPI.org

The most comprehensive source of information on synchrophasors is www.naspi.org, hosted by the North American SynchroPhasor Initiative (NASPI). NASPI is a collaborative effort between the US Department of Energy, the North American Electric Reliability Corporation, and North American electric utilities, vendors, consultants, federal and private researchers and academics. NASPI activities are funded by DOE and NERC, and by the voluntary efforts of many industry members and experts.

Here are three single-sheet success stories in the application of synchrophasors to real-time control:

Smart Anti-Islanding Using Synchrophasor Measurements
https://www.naspi.org/site/Module/Stories/smart_anti_islanding.pdf

Using SynchroPhasor Technology to Detect and Manage High Frequency Oscillations Caused by HVDC Pacific Intertie
https://www.naspi.org/site/Module/Stories/synchrophasor_detect_manage_high_frequ_oscill_20110321.pdf

Using Synchrophasor Measurements for Wide-Area Situational Awareness to Improve System Reliability
https://www.naspi.org/site/Module/Stories/using_synchro_measure_for_wasa.pdf

The informative guideline, companion to 118.1, is IEEE C37.242, *Guide for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMU) for Power System Protection and Control*, to be published in late 2012.

Standardized procedures and automated calibration can greatly reduce the burden of testing and calibrating PMUs. Only a few, custom, non-commercial cal systems for PMUs exist: NIST, China EPRI, Bonneville Power, Virginia Tech. A complex test setup with an expert operator and manual procedures can consume two to six weeks to completely characterize a PMU.

The first Fluke PMU Cal system was delivered to NIST in September of 2011. Beta sites will run through Q1 of 2012. First commercial deliveries will be made in Q2 of 2012.

The US government identified the need for an automated PMU calibration system. Fluke Calibration, under a grant from NIST, has developed the first commercially available, automated PMU calibration system that is:

- IEEE C37.118.1 compliant
- Fast, accurate, and traceable
- With fully documented results

Calibration and standards labs will use the PMU Cal system to verify PMU performance for utilities, PMU manufacturers and government agencies. They will value the system for its accuracy, traceability and repeatability.

PMU manufacturers will apply the system to design verification, first article approval, production test and routine calibration. They will particularly appreciate report utility, limited capital expense and low operating expense.

Electrical generation, transmission and distribution utilities will use the system for type testing, installation/commissioning and troubleshooting. They will welcome the interoperability that comes from standardized PMU testing as well as the sharp reduction in test time, user interaction, user expertise and report generation time.

Phasor measurement units enable real-time computer control to safeguard the stability and reliability of modern power grids. New test and calibration standards for PMUs will promote consistent performance across PMU manufacturers. These standards, applied via the new Fluke PMU Calibration System, will insure PMU interoperability and control costs to permit greater numbers of PMUs to safeguard the Smart Grid.

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