

## **Phasor measurement units gain credibility through improved test and calibration standards**

The North American interconnection, or electric transmission grid, is a complex machine. Minor instability in one part of the grid can lead to catastrophic failure of large parts of the system. Efforts are underway to create a new, Smart Grid. This new grid will be modern and intelligent, utilizing advanced computing, networking and measurement technologies. It will enable efficient energy usage, increased reliability, and integration of alternative energy sources such as wind and solar.

One of these new technologies is a measurement device known as a Phasor Measurement Unit (PMU). PMUs measure voltage, current and frequency, typically at 30 observations per second. The time at which each measurement is taken is recorded with a high degree of accuracy so measurements taken by PMUs in different locations can be synchronized with each other to provide a comprehensive view of the entire grid. Sometimes stand-alone but often built into a protective relay or control component, PMUs play a critical role in monitoring and enhancing stability throughout the Smart Grid. They provide the precision measurements necessary to minimize and control power outages and avoid problems such as cascading blackouts. But to accomplish this, PMUs need to be extremely accurate, reliable and fully interchangeable from model to model. That means PMU calibration standards are extremely important. Presently, PMUs can only be calibrated in a very small number of government and university laboratories. As PMUs are deployed in larger and larger numbers, the power transmission and distribution industry will need a more practical calibration tool.

In February 2010, The United States National Institute of Standards and Technology (NIST) awarded a grant to Fluke Calibration to develop a commercial PMU calibration system that can test PMUs under steady state and dynamic conditions that mimic real world applications, with lower uncertainties than any other tool. Fluke Calibration also hopes to see this calibration system adopted as the de facto standard for testing and calibrating PMUs, so they can be deployed reliably in Smart Grids world-wide. The availability of an economical, off-the-shelf, easy-to-use PMU calibrator will help advance the widespread implementation of PMUs, and thereby, the implementation of a modern energy network.

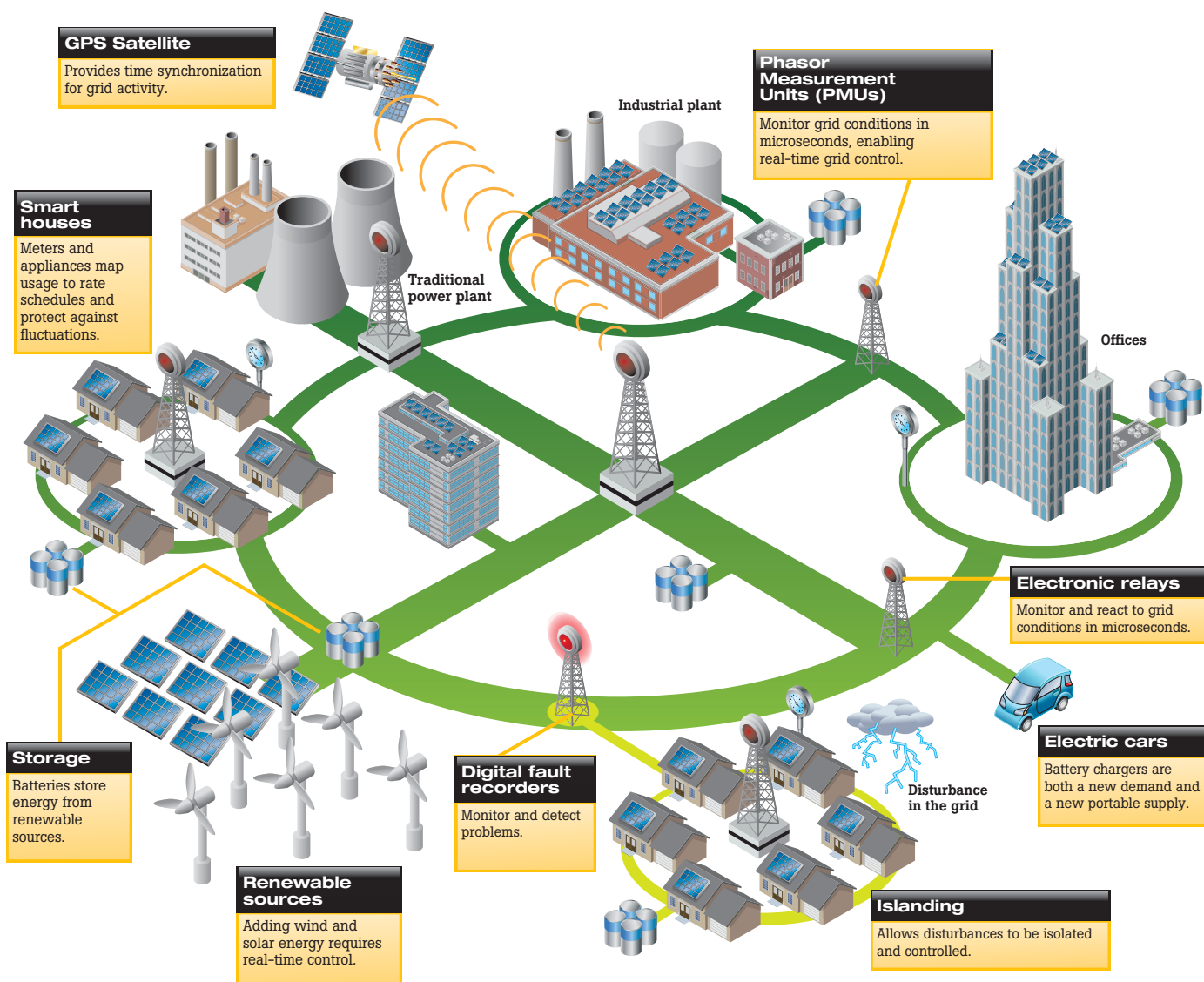
## Monitoring the Smart Grid

The Smart Grid encompasses a wide range of technologies that are designed to jointly modernize the electrical transmission grid. One example is time of day monitoring that will make it possible to charge consumers and businesses more for electricity usage during high demand periods and less during low demand periods. Time of day monitoring is also important in promoting the use of renewable energy sources. Renewable energy sources tend to be intermittent so the power infrastructure must be able to shed demand by raising prices when, for example, the wind stops blowing.

A critical aspect of the Smart Grid is the ability to monitor differences in voltage and phase between different sections of the grid. These differences can cause problems such as tripping relays at the point where grid sections are interconnected. Problems can propagate across the network, potentially causing a cascading blackout such as the 2003 Northeast Blackout. The U.S.-Canada team that investigated this blackout recommended that PMUs be installed across North America to understand real-time grid conditions. The investigation hypothesized that if such a system had been in operation the blackout could have been avoided by identifying, understanding and mitigating the conditions that were its root cause.

## Smart Grid

A real-time, dynamic network of electrical demand, supply, and control



As the primary measurement and sensing tool in the Smart Grid, PMUs will play a broader role beyond avoiding blackouts. PMU data will be used to improve transmission and distribution efficiency by increasing line throughput and reducing line losses. Southern California Edison is already using PMUs to drive the automated control of static volt-amperes reactive (VAR) compensators (SVCs). The Bonneville Power Administration (BPA) uses PMUs for a real-time stability control system. BPA, American Electric Power (AEP) and the Tennessee Valley Authority (TVA) are also working to incorporate PMU data to improve the accuracy and sampling rate of their state estimation tools. PMU data is also being used to calibrate simulation models to improve power system planning.

More than 2000 PMUs are already installed worldwide. In 2009, the US government announced an investment of \$3.4 billion in energy grid modernization, via the Smart Grid Investment Grant

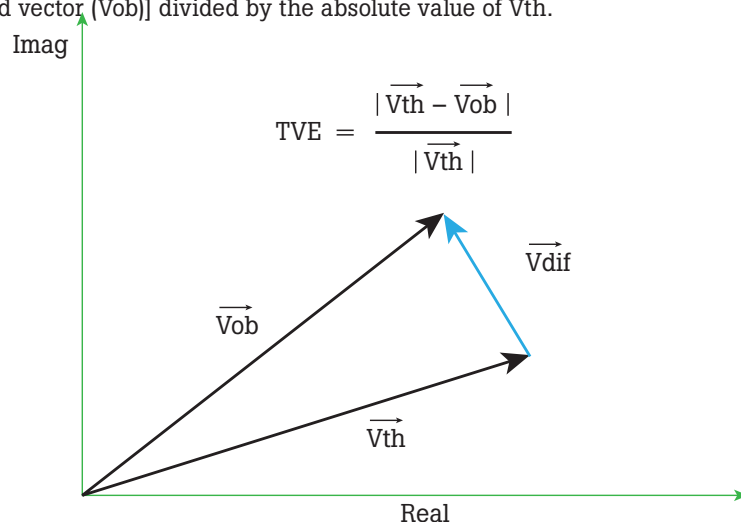
(SGIG). This investment will include the installation of more than 850 PMUs that will monitor the complete US electric grid. According to the North American Synchrophasor Initiative (NASPI), PMUs will be installed at the following locations by 2014:

- Major transmission interconnections and interfaces
- All 500 kV and above substations and most 200 kV and above substations
- Generator switchyards and even on some individual generators in plants with 500 MW or higher capacity
- Major load centers
- Large wind generator, solar and storage locations
- Other locations to assure observability in areas with sparse PMU coverage

## PMUs need to be accurate, repeatable and interchangeable

The accuracy and repeatability of PMUs are critical to fulfilling the promise of the Smart Grid. However, the current standard governing PMU performance (IEEE C37.118.1-2005) is quite broad. Testing by NIST has shown that PMUs from various manufacturers can report dynamic conditions very differently. For example, signals pass through an anti-aliasing filter that generates some level of error. Next, the signal passes through an analog/digital (A/D) converter that can introduce magnitude or gain error and channel phase shift. Signal processing to evaluate the phasor magnitude and phase angle which may create additional error. The phase is reported with respect to the global time reference, so errors in the global positioning system (GPS) source and cable delays may introduce synchronization errors.

Total vector error is equal to the absolute value of  $V_{dif}$  [the difference between the theoretical vector ( $V_{th}$ ) and the observed vector ( $V_{ob}$ )] divided by the absolute value of  $V_{th}$ .



The Power Systems Relaying Committee (PSRC) of the IEEE Power Engineering Society developed a standard that quantifies the performance requirements of PMUs. Published in December 2005, The Standard for Synchrophasors IEEE C37.118-2005 defined the uncertainty requirements for the PMUs in terms of the total vector error (TVE) which combines both magnitude and time synchronization errors. The standard specifies maximum allowable TVE errors under various operating conditions. These conditions include frequency, voltage, current, and phase angle, as well as levels of harmonic distortion and out of band frequency distortion. Now, the PSRC has ratified a new standard, IEEE C37.118.1-2012, that updates and clarifies the existing steady state tests and adds new dynamic tests.

## Need for a practical PMU calibration tool

The ability to test and calibrate PMUs will be required by anyone who depends on the performance of these devices. The goal of PMU calibration is to ensure that all PMUs are interoperable regardless of their make and model and comply with the latest 118.1 standard. A general rule of thumb is that a calibration system has to have less than one-fourth of the total uncertainties of the system under calibration. The North American Synchrophasor Initiative (NASPI) has prepared a PMU System Testing and Calibration Guide to establish common methods for calibrating PMUs. This guide is approaching ratification and will be published as IEEE PC37.242.

The Electric Power Research Institute (EPRI) summarized the calibration challenge as follows: “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 systems. Utilities need the guarantee of reliability and accuracy of PMUs and also the seamless interchangeability among PMUs from different vendors before they will invest heavily in them.”

NIST developed a test system that calibrates PMUs against the performance requirements of the IEEE C37.118-2005 standard. Using a commercial three-phase power simulator, the calibration system provides UTC-synchronized three-phase power signals to the PMU being calibrated. The PMU outputs a C37.118 standard formatted continuous data stream of waveform measurements at a minimum rate of 30 frames per second, each time stamped.

One NIST calibration system performs static testing, while another performs dynamic testing. Static tests hold the input signals to the PMU at various constant levels of voltage, current, frequency and interference signals. Dynamic tests are intended to show the performance of PMUs under varying magnitude and frequency conditions typical of real operating power systems. The NIST calibration system has an uncertainty of less than 0.05 percent TVE. It covers all of the measurement conditions specified in the IEEE standard with several hundred individual tests. The cost, time and expertise required to duplicate this system would be very high. NIST identified the need for a commercially available easy-to-operate system that provides the high levels of accuracy needed for calibrating PMUs.

## NIST awards commercial PMU calibrator grant

In February of 2010, NIST awarded Fluke Calibration a Measurement Science and Engineering Research Grant entitled “Phasor Measurement Units Calibrator Development”. The scope of the grant is to develop a system for calibrating measurements of the magnitude and phase of voltage and current signals in power systems. The 26-month project is be jointly funded by NIST and Fluke Calibration.

The project has four key deliverables:

1. A comprehensive requirements survey based on IEEE C37.118-2005, NASPI PMU testing guidelines and industry experts that understand real-world transient and dynamic PMU testing requirements.
2. Detailed product requirements specifications (PRS) for a PMU calibrator based on the requirements identified in the survey in the first deliverable. The PRS will define steady state testing of PMUs and an appropriate set of dynamic tests that allows the effective adoption of PMUs in the Smart Grid.
3. Design of a commercially available PMU calibrator system that implements the PRS described in the second deliverable.
4. An inter-comparison of PMU measurement capability with the Fluke Calibration Primary Laboratory, NIST and other laboratories which may include PMU manufacturers, universities and China’s EPRI. The purpose of this inter-comparison is to bring further visibility of the need for standardized testing of PMUs and work towards a uniform, global standard for calibrations under both steady state and dynamic conditions.

## Design based on existing electrical power standard

Fluke Calibration has enlisted subject matter experts from academia, industry and government that have extensive experience and knowledge of PMUs and synchrophasor standards. Focus was placed on understanding real world applications of PMUs and translating the application requirements into specifications for a PMU calibration system. Next, thorough examination of commercially available PMUs, their applications and test methodologies was conducted. This information was used to specify calibration techniques across platforms. Fluke Calibration engineers then designed a highly accurate and precise system capable of testing and calibrating PMUs from any manufacturer.

The PMU calibration system is built around the Fluke Calibration 6105A Electrical Power Standard. The 6105A is an ideal platform for PMU calibration because of its 0.003 degree phase angle accuracy and ability to accurately generate the required distorted signals. The 6105A digital subsystem will be modified to facilitate synching to GPS time, among other changes.

The PMU calibration system will help calibration labs, PMU manufacturers and utilities ensure the accuracy and interoperability of PMUs across different vendors. Overcoming this hurdle will encourage utilities to deploy more PMUs in the Smart Grid. The end result will be fewer outages, improved power quality, increased energy efficiency and greater stability, even with a multitude of renewable energy sources on the grid.