Benefits of Synchrophasor Applications for Electrical Grid Management

For over 100 years, phasor information has been used by power system engineers to analyze power system performance. Over the past 30 years, Synchrophasor applications have been used by electrical utilities to give them a real time view of electrical grid conditions. Synchrophasor technology enables the direct measurement of the current state of the power system. A synchrophasor is a Universal Time Coordinated (UTC) synchronized phasor measurement of the fundamental power system components of voltage, current, and other electrical parameters at bus locations on the grid.

The North American SynchroPhasor Initiative (NASPI), a collaboration between the electric industry, the North American Electric Reliability Corporation (NERC), and the U.S. Department of Energy (DOE), was developed to advance the use of synchrophasor technology. This technology enhances "grid reliability through high-speed, wide area measurement, monitoring and control."[1]' The Utility industry has started to recognize value proposition and is at the transition point to make phasor measurement units (PMUs) part of their procurement standard and supply chain process. Today, PMU devices are used in many different applications in generation, transmission, and distribution, from equipment performance to system monitoring. Initial locations have been primarily on the transmission grid. However, with the addition of significant renewable energy generation and new loads on the distribution grid (e.g. EV car charging), there are growing pilot installations and deployment in distribution infrastructure. In some instances, the DOE, through public Funding Opportunity Announcements (FOA), has been a cost share partner in innovative distribution projects covering applications beyond the substation, involving pad / pole mount locations.

Three-phase and/or sequence component monitoring with PMUs has enabled real time access (dozens of milliseconds) to real time angle and reactive power of frequency, rate of change of frequency (ROCOF), voltage and current phasors, and complex power. In many instances, remote terminal units (RTUs) only monitor a single-phase value of voltage and current. Frequency for real time operation has been available from only a limited number of locations across the entire system, and the health of the power grid primarily has been assessed based on equipment in-service / out of service (steady state conditions), and substation voltages.

Today, information from a substation is generally provided by what is known as a supervisory control and data acquisition (SCADA) system. SCADA systems are typically operated in a "polled" mode of operation with polling occurring every two to eight seconds. Although adequate for some applications, the polling rates do not capture the more complex and dynamic events that occur on the grid. Specifically, sub-synchronous system oscillations over the range of 0.01 Hz to 55 Hz are not identified, and events greater than 0.5 Hz are not captured or analyzed. Oscillography can identify some oscillations, however, a 0.01 Hz oscillation (as would be induced by a solar magnetic event) would require 100 seconds of data to see a *single* cycle of this oscillation.

[1] "Summary of the North American SynchroPhasor Initiative (NASPI) Activity Area," U.S. DOE, June 2012

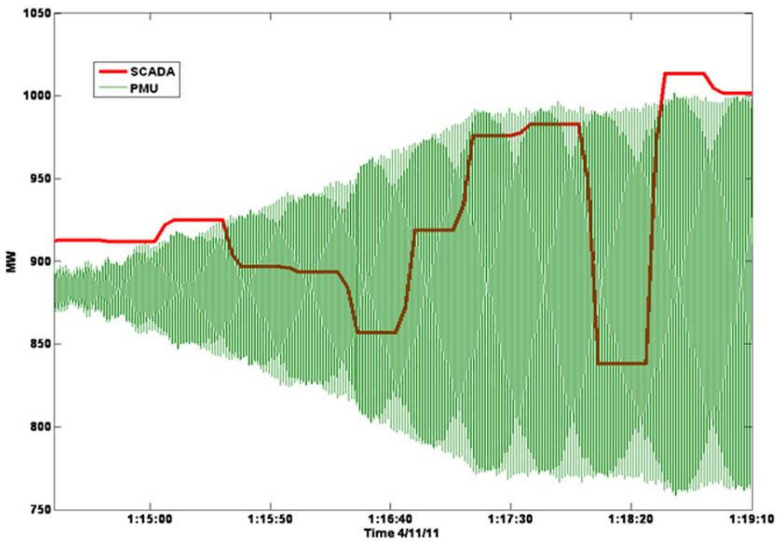

Figure 1 - SCADA (Red) vs. PMU (Green) View of an Oscillation[2]

Figure 1 is an example of recordings at a grid dispatch center, from a generator with high damping oscillations. The green waveform is a recording from a PMU with a 60 measurement per second rate, clearly showing an undamped oscillation. The red wave on top of the green one is from a SCADA RTU. Notice the level of data captured by the PMU vs. the slow recording from the RTU. The 2 second sample rate from the RTU "aliases" the underlying signal. In this example case, the power plant operator only has SCADA information, and does not see the oscillation. The PMU measurements are located on the plant's transmission outlets; therefore, the system operator (dispatcher) with visual access to both the SCADA and the PMU recordings can alert the plant operator about the oscillation and together they can coordinate to quickly ramp down plant output power before any damage occurs. Today, there are more than 40 different applications enabled by the availability of Synchrophasors.

Synchrophasor Details

According to the IEEE C37.118.1 standard, the time when a Synchrophasor measurement is made is based on UTC and configured in the device to a specific periodicity. For example, if the selected reporting rate is 60 measurements per second, each measurement would occur every 16.66 ms, starting from the top of second or when the millisecond portion of the timestamp is "0." The reporting rates that must be supported are noted below:

- 60 Hz: 10/12/15/20/30/60
- 50 Hz: 10/25/50

Like a phasor, the Synchrophasor reports the fundamental frequency magnitude (scaled to RMS) and phase angle, timestamped per the UTC measurement "strobe." Subsequent measurements are made per the user-specified periodicity.

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[2] "Diagnosing Equipment Health and Mis-operations with PMU Data," by Alison Silverstein, NAPSI Technical Report, May 1, 2015; accessed 2/22/2024 from chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.naspi.org/sites/default/files/reference_documents/14.pdf?fileID=1530

The standard key components of Synchrophasor systems are:

- Multiple phasor measurement units (PMU)s.
- One or more phasor data concentrators (PDC)s.
- A communication framework for transmitting data.
- A control, monitoring, or visualization application.

The IEEE C37.118.1 standard defines two classes of Synchrophasors that can be streamed by a PMU. These classes are:

- **The P-Class or Protection** class has a small window size (2-cycle triangular data filtering) that supports fast response. It is required for transient conditions such as transient recovery conditions and fault events.
- **The M-Class or Measurement** class, has a larger window size (7-cycles window to integrate measured values), with measurements that are more precise. It is used for steady state and dynamic events such as oscillation.

The Nexus® 1500+ PMU supports both classes and streaming rates. The selectable streaming rate allows the desired data class and suitable data frame for the specific applications. Figure 2 shows a sample comparison of IEEE C 37.118.1 “P” and “M” class data for 120 frames and 60 frames per second respectively from field measurements.

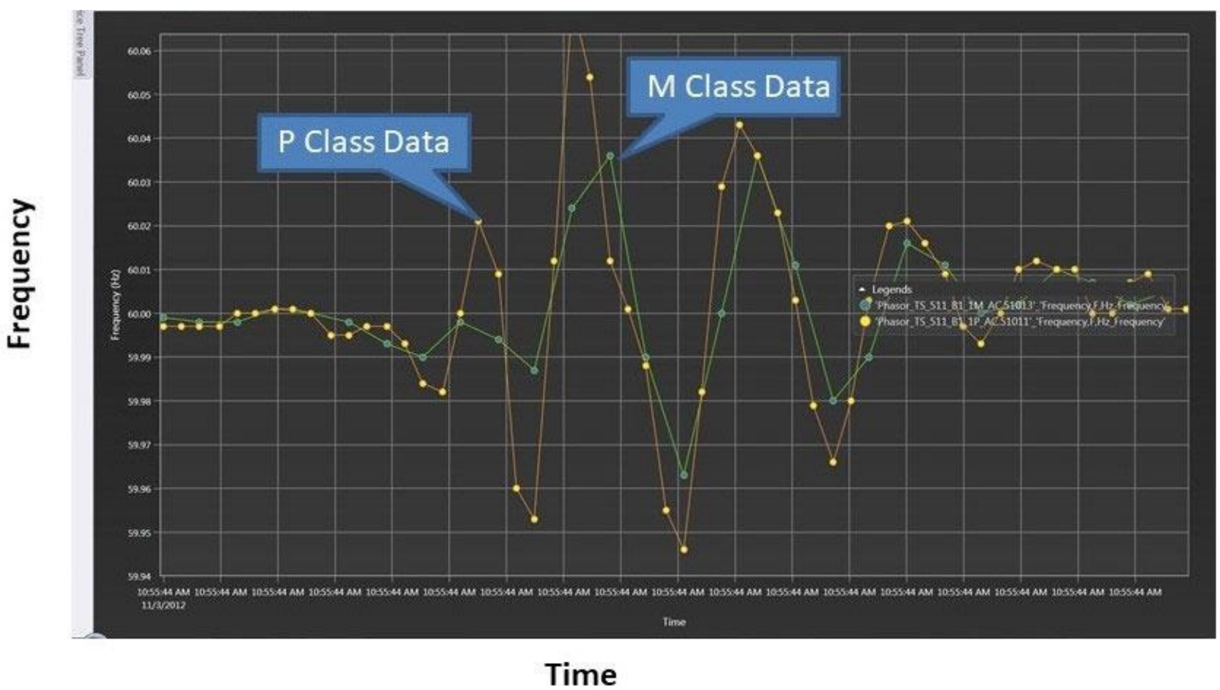

Figure 2 – PMU “P” and “M” Class for Frequency Measurement

Synchrophasor Communication

As noted earlier, Synchrophasor data is continuously streamed from the PMU computing device, effectively providing a movie-like view of the state of the power system. Although the original Synchrophasor communication links were RS232/serial interface, almost all installations today communicate via Ethernet. Most products today implement Unicast communications as per the IEEE

C37.118-2 standard, which is point-to-point or Unicast. When communicating point-to-point, the user can choose how the protocol responds to lost data packets. When transmitting at higher rates, the User Datagram Protocol (UDP) is a better option, as missing data is just ignored by the client. The client/receiver does have an option of “estimating” the lost data values through interpolation between adjacent received values. The standard mentions the option of Multicast communications; however, it is silent on the implementation details, so interoperability is problematic.

The data (some fixed / some user configurable) that can be communicated from the Nexus® meter as PMU includes:

- Header information [18 bytes - fixed].
- Timestamp [8 bytes - fixed].
- Frequency [2 or 4 bytes – format selectable].
- Rate of Change of Frequency [2 or 4 bytes – format selectable].
- Phasors [24 to 144 bytes – user selectable].
- Analogs [0 to 64 bytes – user selectable].
- Digital Status [0 to 2 bytes – user selectable).
- Cyclic Redundancy Check (CRC – 2 bytes - fixed).

The Nexus® 1500+ Meter Synchrophasor PMU offers both power quality measurements and PMU functionality, paving the way for power systems to be observable with warnings, assisting utilities and independent system operators (ISOs) with accurate modeling, and helping with accurate time stamped data for post event analysis, and discovering the root cause of previously unexplained oscillations.

Example Application

State Estimation (SE)/Measurement - Traditional SE tools have been designed to solve for the system state (positive sequence voltage and angle at each bus) using Watt and Var measurements, without times tamped data from substations throughout the system. Hence, depending on the time RTU data arrives from various locations, an “estimate” of the system would be available to the system operator. Figure 3 is an example of this information presented to the system operator.

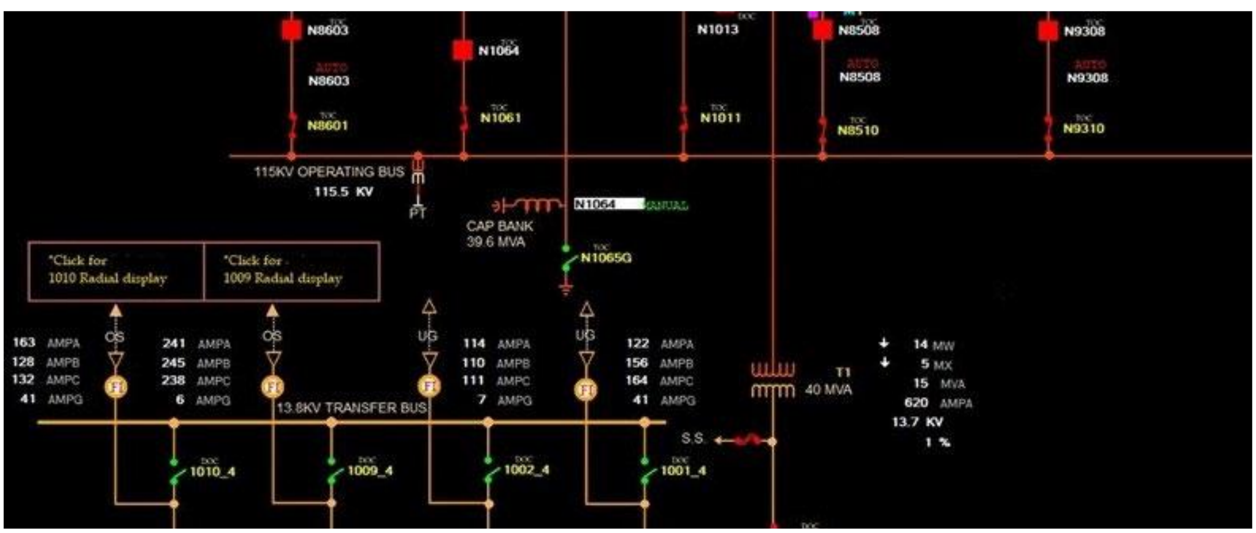

Figure 3 – Example Station Display from a Substation without PMU

There are two variants of SE that integrate PMU data into the solution. The first variant is the Phasor Assisted State Estimator, which uses several Synchrophasor measurements from around the grid as "anchor points." These are used in the SE solution to improve the accuracy of the SE output's linear state estimation. A second technology is a three-phase Linear State Estimator where the computation is a matrix multiplication and does include detection of bad data.

With power systems becoming more integrated, proliferation of new energy sources interconnecting at transmission or distribution, more demand on equipment availability, and emphasis on efficiency, the system's state today is much more dynamic than in the past. Availability of time synchronized measurements and SE solutions to identify bad data, have resulted in new system views with reactive power and phase angle, screen displays with warnings, and audible alerts of dynamic changes in system conditions. Figure 4 is a substation view of a high voltage switchyard with some lines, transformers, and a high voltage connection to a power plant equipped with PMUs. The PMUs display angles in the form of speedometers. Notice colors within the angle monitoring speedometers: green indicates desired operating angle, yellow is a warning of exceeded threshold, and red is a danger area.

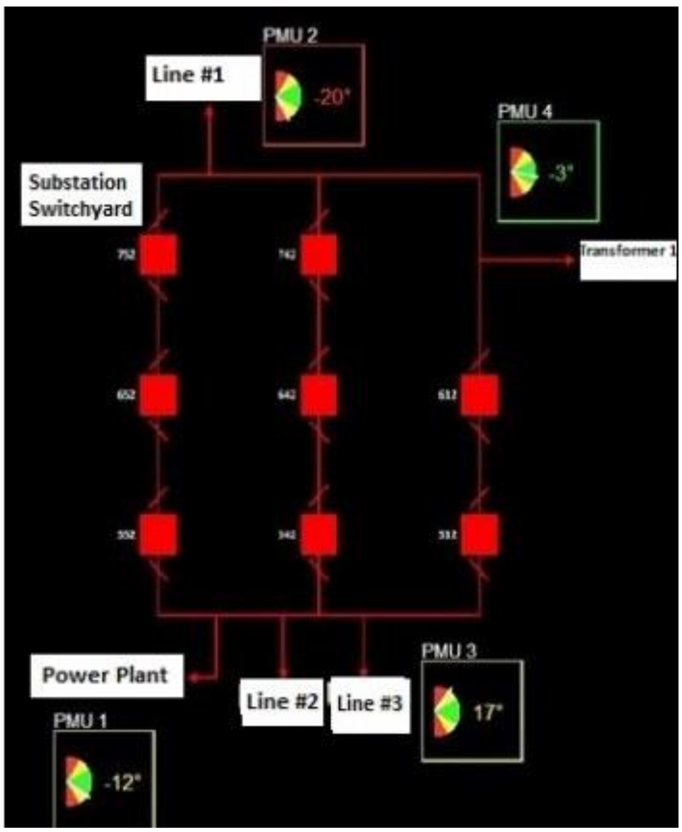

Figure 4- EMS Station View with Some PMU Devices Displaying Angle

Conclusion

The Nexus® 1500+ Meter Synchrophasor PMU offers power quality and PMU functionality and can assist in a variety of applications in generation, distribution, and transmission. Today, there are more than 40 different applications where results from production PMUs are harvested: from equipment underperforming, such as a slow breaker or a generator oscillating out of synch, to situational awareness of the power grid during dynamic system conditions, to real time operation influenced by the influx of intermittent renewable resources, to power flow modeling validation and post-event analysis. Conventional operating procedures are becoming less effective without PMUs. Contingency analysis based on actual values is needed to manage major system corridors from congestion. The new challenges such as hybrid HVDC/HVAC also require PMU devices to determine the root cause of previously unexplained oscillations.