Testing Phasor Measurement Units using IEEE 1588 Precision Time Protocol

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Abstract **— As the electric power grid is changing to a smarter more dynamically controlled system, there is increasing need for measurements that show the global status of the system for wide-area monitoring and control. These measurements require time synchronization across the grid. This synchronization is obtained by the use of GPS clocks. As the number of such synchronized devices increases there is a need to have an efficient, accurate, and reliable method of time distribution within power substations. The power industry is increasingly turning to the use of IEEE 1588 network Precision Time Protocol to meet this need in substation Intelligent Electronic Devices (IEDs). This paper examines this need in relation to the use of Phasor Measurement Units. This also paper describes the errors associated with this protocol and its application to the calibration of PMUs.**

Index Terms **— Calibration; Coordinated Universal Time (UTC); Global Positioning System (GPS); Intelligent Electronic Devices (IEDs); Phasor Measurement Units (PMU); Precision Time Protocol (PTP).**

I. Introduction

There is an ongoing effort to update the U.S. electric power grid and design the new Smart Grid. New construction is constrained by legacy systems, while performance requirements have dramatically changed. The increased need for real time monitoring and control of the power system at the local and wide-area levels is pushing requirements for better data quality and dynamic situational awareness.

The measurements to support these changes must reflect the state of the system across an entire interconnect. This data is being obtained from globally time synchronized measurement devices such as Phasor Measurement Units, PMUs. With the increase in such devices, the use of network time distribution within the substation becomes more important. Network-based time synchronization can simplify existing IED design by using the network port to synchronize time rather than requiring a GPS antenna or a separate timing signal port for each device.

NIST has developed a test system for PMUs and updated it to accommodate IEEE 1588 Precision Time Protocol [1]. Test results for a PMU using PTP are presented.

II. Time Distribution

IEEE 1588-2008, the second version of PTP, improves the accuracy, precision, and reliability of time synchronization over networks. Hardware time-stamping at the physical layer of the Open Systems Interconnection model (OSI model) is key. IEEE 1588v2 also introduces the concept of Transparent Clocks (TC), which are switches that measure the residence time of each packet going through it. This reduces significantly the asymmetrical delays introduced by switches, and almost eliminates the impact of network load and its variations on time synchronization accuracy [2].

The reliability of IEEE 1588v2 can be enhanced by adding redundancy at multiple levels. First, using a ring protocol allows a switch or a network connection to be broken without impacting the 1588 PMU. Secondly, the Best Master Clock Algorithm (BMC) allows for multiple time synchronization sources and automatically switches between Grandmasters (GMs) if necessary. The sub-microsecond accuracy is maintained during a GM switchover [3].

IEEE C37.238 [4] specifies a profile for the use of IEEE 1588 PTP in electric power systems. The profile was designed to be used for precise time synchronization of devices in an electric power substation, and between substations in a larger geographic area. The standard is based on the assumption that all devices participating in the time distribution support the standard.

III. PMU Testing

PMUs are tested according to the IEEE Synchrophasor Standard C37.118.1-2011 [5]. This standard uses the performance requirement of Total Vector Error, TVE, limits. The NIST PMU testbed [6] has been updated to perform the tests of this new PMU standard.

The normal NIST test setup is shown in the upper part of Fig. 1. A GPS clock synchronizes to UTC with an uncertainty of ±45 ns and outputs an IRIG-B signal, a pulse per second (PPS), and a 10 MHz signal. These three signals are provided to a waveform generator that produces three-phase voltages and current waveforms, sampled by the PMUs under test. The PMUs report their results by sending IEEE C37.118 messages and the results received are used to evaluate the PMU.

The 1588 PMU test setup is shown in the lower part of Fig. 1. An IEEE 1588 GM synchronizes to UTC via GPS. An IEEE 1588 Ordinary Clock (OC) is added to a commercial PMU to create a virtual 1588 PMU shown in the blue box. The OC synchronizes by exchanging IEEE 1588 messages with the GM. The OC then provides an IRIG-B and a PPS output that are fed into a traditional PMU. Note that the PMU we tested required a fiber optic PPS input. Our OC only provided a copper PPS output, hence the use of the copper to fiber optic adaptor shown in the diagram.

We used a scope to evaluate the quality of the time synchronization, by monitoring the PPS output of the GM as well as the PPS and IRIG-B outputs of the OC. These differed on average by about 5 ns with a 10 to 15 ns standard deviation.

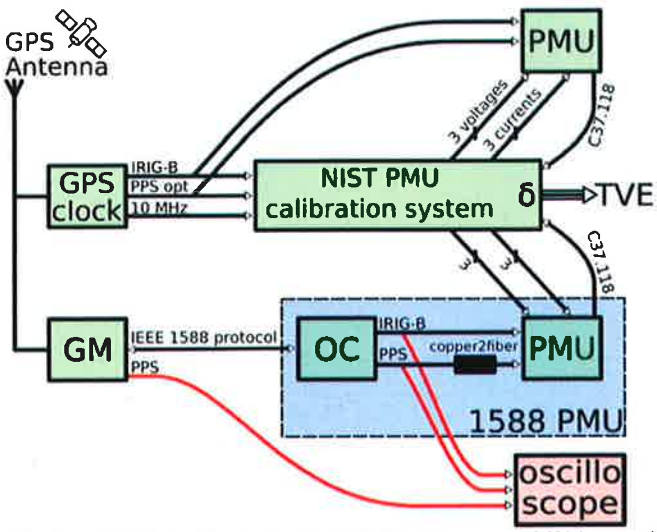

Fig. 1. Test setup for evaluating PMUs. The upper PMU is tested using signals directly from a GPS clock. The lower PMU is tested using signals sent via IEEE 1588 protocol to an Ordinary Clock, which is generating the IRIG-B and PPS signal for the PMU.

IV. Test Results

To demonstrate the effectiveness of the 1588 timing system a comparison was made of the performance of a PMU synchronized with either direct connections to a GPS clock or an IEEE 1588 GM. This was done by performing the frequency variation test on the same PMU twice. The frequency variation test was first done with the conventional IRIG-B and PPS signals from a GPS clock. Then the test was done a second time with the IRIG-B and PPS signals from a 1588 controlled OC as shown in Fig. 1. The NIST test system has an uncertainty of 0.03 % in magnitude and a time uncertainty of 800 ns. The combination gives a TVE of 0.05 %. The IEEE C37.118.1 requires the PMU to have a maximum TVE error of less than 1 % for various frequency ranges depending on the nominal frequency and the PMU's reporting rate.

The frequency variation tests were performed with input signal frequencies from 55 Hz to 65 Hz as required for a reporting rate of 60 reports per second. The maximum TVE values for the frequencies for the PMU connected directly to a GPS clock or via 1588 are shown in Fig. 2. Also shown is the difference between the two sets of phase error measurements. Much of the differences are from the normal variations in the PMU values and the NIST values. Note that all the differences are less than the NIST test system uncertainties.

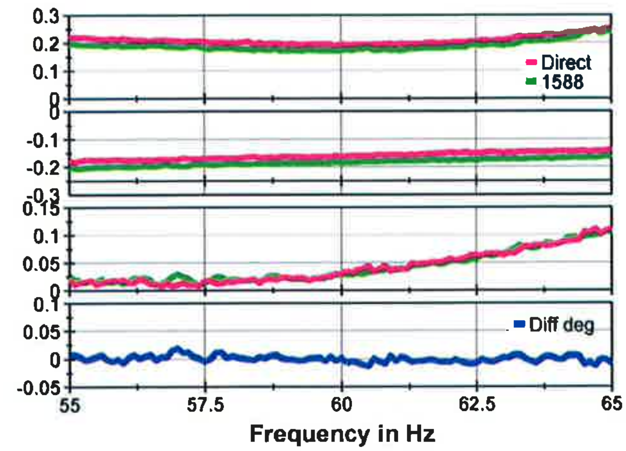

Fig. 2. Total Vector Error (TVE) for phasor VA (top), magnitude error in %, phase error, and phase difference in degrees (bottom) versus frequency. Time is from GPS directly or over a network via IEEE 1588.

VI. Conclusions

The need for dynamic monitoring of modern electric power grids is increasing the number of globally synchronized measurement devices. This increase requires a more efficient method for accurate time distribution within substations. This paper discusses the PTP and its application to substation time distribution and to PMU testing. The causes of uncertainty in such time distribution systems will be described. This method has been demonstrated in a test on a PMU for frequency variation. The results show that PTP is as accurate as a direct GPS clock connection for testing and use of PMUs. With adequate care in the installation of the network systems in electric power substations, this time distribution protocol will provide an efficient and reliable method of time distribution.

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