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Testing and Calibration of Phasor Measurement Units (PMU)

K. S. Meera* and Kaliappan Perumal

CPRI, Bangalore, Karnataka, India; meera@cpri.in

Abstract

Phasor Measurement Units (PMUs) and Phasor Data Concentrators (PDCs) are the fundamental components of Wide Area Measurement Systems (WAMS) and Wide Area Monitoring Protection and Control Systems (WAMPACS). PMUs provide fast time-stamped measurement of system parameters such as voltage, current and frequency. They have communication features which help in exchange of large quantities of data quickly. As these measurements are very useful in power system support applications such as system parameter analysis, online voltage stability calculations, adaptive protective algorithms etc. they must always function reliably and accurately. This necessitates that the PMUs be calibrated so that their data is consistent, accurate, and credible, and that the models from different manufacturers are interoperable. The 6135A PMUCAL of fluke make is a unique tool which carries out manual/ automated tests that certify a PMU configuration for meeting the latest performance standards of the IEEE Standard for Synchrophasor Measurements for Power Systems (IEEE C37.118.1:2011, IEEE C37.118.1:2014 and IEEE C37.242). This paper discusses the 6135A PMUCAL – a unique test facility set up at the Power Systems Division of CPRI and also results of typical PMUs tested using this facility.

Keywords: Global Positioning System (GPS), Phasor Measurement Unit, Rate-of-change-of-Frequency Error (RFE), Synchrophasor, Total Vector Error (TVE)

1. Introduction

Wide Area Measurement Systems (WAMS) are increasingly being used to monitor power systems in terms of static and dynamic performance. With the addition of new energy sources, such as solar, wind, etc. the power grid observability has assumed more importance to prevent future blackouts. The healthy functioning of the power grid is closely linked to the phase differences of the phasors in the grid. Therefore, the determination of these differences requires the synchronization of the measurements at the required locations of the power system. The Phasor Measurement Unit (PMU) provides good observability of the state of the grid as it provides fast time-stamped measurement of system parameters such as voltage, current, phase angle and frequency. PMU measurements are often taken at of 25, 30, 50 or 60 measurements per second and each measurement is time stamped to a common time reference provided by very high precision clocks (coordinated universal time (UTC) derived from the Global Positioning System (GPS)), thereby synchronizing the Synchrophasors from different locations. When data from various PMUs are combined together, the information provides a comprehensive view of the grid condition, and is often used to trigger corrective actions to maintain reliability.

As a primary measurement and sensing tool in the Smart Grid, PMUs will play a broader role beyond avoiding blackouts. PMU data can also be used to manage real-time grid operations 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)

Author for correspondence

for reactive power support and 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. Reference[1–4] discusses the other possible applications of PMU's.

A number of commercial PMU's are now available in the market. Thus the performance of each individual PMU would be an important aspect that could directly affect the performance of the power system. The IEEE standard C37.118.1-2011[5], defines the synchrophasor measurements used in power system applications. This standard specifies the compliance requirements for PMUs with respect to the phasor magnitude, frequency, phase angle, harmonics distortion, and out-of-band interference. It defines the uncertainity requirements for the PMUs in terms of Total Vector Error (TVE). This error measurement assures that PMUs have limited uncertainty in both their magnitude and time-synchronization errors. Thus a tool that certifies a PMU configuration for meeting the latest performance standards of the IEEE Standard for Synchrophasor Measurements for Power Systems is required.

Presently, calibration of a PMU occurs only at a few select locations including NIST, China EPRI, Bonneville Power Administration and Virginia Tech. For meeting the above requirements of testing and calibration of PMU's, Power Systems Division of Central Power Research Institute has acquired 6135A PMUCAL test facility from M/s Fluke, Norwich, UK. The features of the PMUCAL test facility and also results of typical PMUs tested using this facility is being discussed in this paper.

2. Phasor Measurement Concepts

PMU's are installed at all important locations in a power system network. These PMUs are accurately time synchronized, through the Global Positioning System (GPS). Based on this time reference, the magnitudes and phases of voltages and currents at the PMU locations are measured, exactly at the same times in all locations (Figure 1). The measured values of voltages and currents are available as complex phasors and as they are synchronously measured (time stamped) values they can be easily compared and processed.

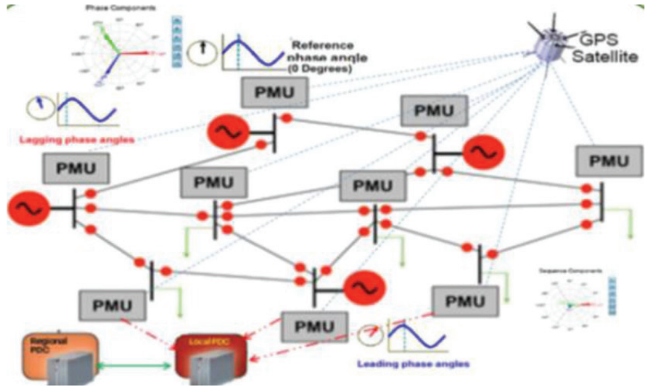

Figure 1. Synchronized Phasor measurements in a Network.

Figure 2 shows the block diagram of the signal processing model of a PMU.

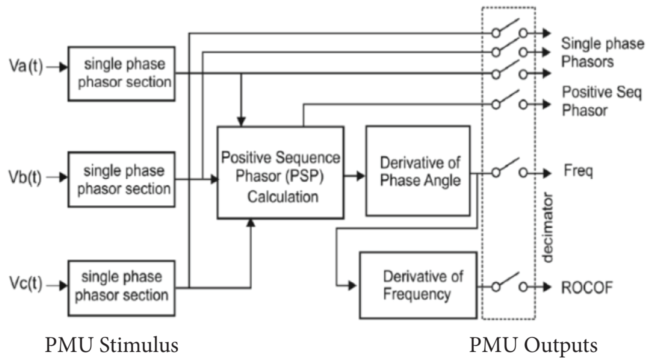

Figure 2. Signal Processing Module of PMU.

The externally applied stimuli applied are on the left, while PMU outputs are on the right. Three single phase estimators are combined to create a Positive Sequence Phasor. The derivative of the positive sequence phasor is the frequency and the derivative of frequency is the Rate of Change of Frequency (ROCOF). The decimator band limits and reduces the internal data rate of the PMU to the external reporting rate.

2.1 Principles of Synchrophasors

Synchrophasors are precise time-synchronized measurements of parameters on the power system grid, available from grid monitoring devices called Phasor Measurement Units (PMUs). A phasor is a complex number representing both the magnitude and phase angle of voltage and current sine waveforms (50 Hz) at a specific instant in time. Each phasor measurement is time-stamped against Global Positioning Systems universal time. A phasor measurement with time-stamp is called a Synchrophasor[6]. The measurement convention for Synchrophasors is to define the observed waveform with respect to its cosine i.e., the reported phase is the angular difference between the instant of the reporting time and the instant the waveform is at its peak (Figure 3).

IEEE Standard C37.118 provides operating guidelines for the synchrophasor measurement system, including the format of the time tag and time synchronization, communication format and data structure, reporting rates, and accuracy limits.

The theoretical values of a synchrophasor representation of a sinusoid and the values obtained from a PMU may include differences in both amplitude and phase. Although they could be separately specified, the amplitude and phase differences are combined together in the C37.118.1 standard in a quantity called **Total Vector Error (TVE)**.

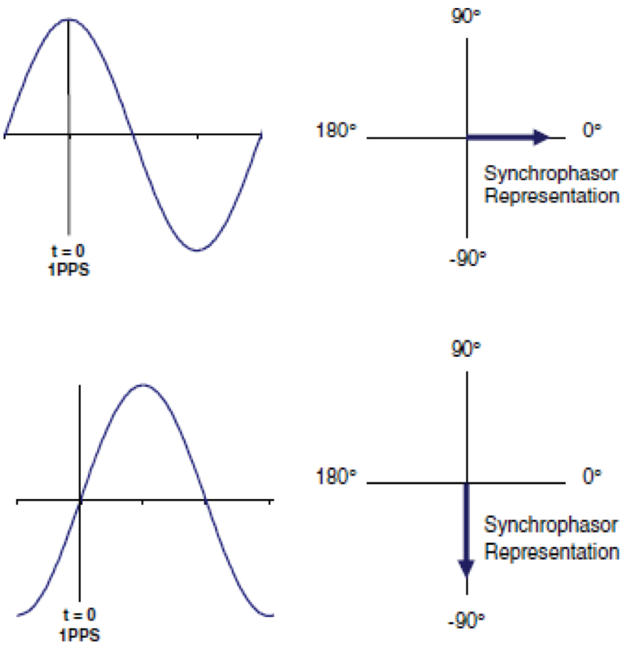

Figure 3. Phasor representation.

Thus the TVE is a combined measure of three sources of error viz. magnitude error, phase error and timing error. It is an expression of the difference between a 'perfect' sample of a theoretical synchrophasor and the estimate given by the Unit Under Test (UUT) at the same instant of time. Equation (1) (below) gives the expression for TVE.

$$TVE(n) = \sqrt{\frac{(\hat{X}_r(n) - X_r(n))^2 + (\hat{X}_i(n) - X_i(n))^2}{((X_r(n))^2 + (X_i(n))^2)}} \quad (1)$$

Where $\widehat{X_r}$ and $\widehat{X_i}$ are the sequences of estimates given by the PMU under test, Xr and Xi are the sequences of theoretical values of the input signal. Figure 4 below shows the graphical representation of the synchrophasor error.

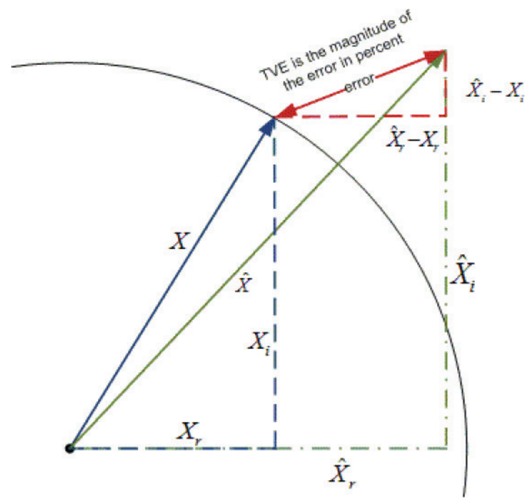

Figure 4. Graphical representation of synchrophasor error.

Similarly, **frequency and rate of change of frequency (ROCOF)** errors are the absolute value of the difference between the theoretical values and the estimated values given in Hz and Hz/s respectively. The measured and true values are for the same instant of time, which will be given by the time tag of the estimated values.

$$F_{\text{Error}} = [\, f \downarrow \text{measured} - f \downarrow \text{true}]$$
$$ROCOF_{\text{Error}} = [(df/dt) \downarrow \text{measured} - (df/dt \ \text{true}) \downarrow]$$

Another important factor to be considered in real time application of PMU's is the reporting Latency. Latency in measurement reporting is the time delay from when an event occurs on the power system to the time that it is reported in data. For all practical purpose, the PMU reporting latency is defined as the maximum time interval between the data report time as indicated by the data time stamp, and the time when the data becomes available at the PMU output.

Sufficiently low reporting latency is to be guaranteed, to ensure that the PMU measurements are made available in a reasonable time. Many internal and external factors affect the overall latency of the output data of a PMU connected to a PDC. The Standard IEEE C37.118.1-2011 defines the latency pertaining directly to the PMU.

A list of references regarding synchrophasors and PMUS's are provided in references[7–11].

3. PMU Calibrator

The Fluke Calibration 6135A/PMUCAL Phasor Measurement Unit Calibration System is a measurement and calibration device for calibration and testing both P class and M class PMU's (P - protection class – applications requiring narrow operating range and fast response and M class - measurement class - applications requiring full operating range and greater precision).

The integrated 6135A/PMUCAL system fully complies with the IEEE C37.118.1a-2014, IEEE Synchrophasor Measurement Test Suite Specification -Version 2-2015 and C37.242-2013 standards for PMU operation and verification. The system also fully complies with the 2016 draft standard IEC/ IEEE 60255-118 Ed.1.

The main features of the calibration system are:

- Simulates static and dynamic conditions (static tests and dynamic tests) that a PMU can experience in a power grid.
- Test a PMU against the performance standards as per IEEE C37.118.1- 2011 (Synchrophasor Measurements for Power Systems) and IEEE C37.118.2 (Synchrophasor Data Transfer for Power Systems).
- Calibrate and test a PMU from a desktop PC using the PMU Calibration Software.
- Manually run single tests or use the factory built-in automated test procedures
- Generate Calibration reports

The 6135A PMUcal system is made up of the following hardware components:

- **Three-phase 6135A Electrical Power Standard**: Includes one 6105A Electrical Power Standard Master Unit and two 6106A Electrical Power Standard Auxiliary Units. Provides voltage and current signals to the PMU under test
- **6105A System Timing Unit***:* controls timing and synchronizes the tests done throughout the calibration system
- **GPS receiver**: supplies the 6135A/PMUCAL system and the PMU under test with a source of Universal Coordinated Time (UTC)
- **Server PC**: functions as a dedicated application controller, receiving commands from the client PC to control the calibration system.

The calibration software resides on the server PC and is the control interface to the 6135A PMUCAL system[12]. It enables the test engineer to (a) configure the testing process and control the testing and calibration of the PMU under test (b) analyze the test results. It supports two modes of testing (a) *simulation mode* (simulates the virtual PMU responses in order to do test development) or (b) *test mode* (enables testing of a physical PMU) connected to the calibrator.

4. Static Tests/Steady State Compliance Test

These tests are carried out to make sure that the PMU's performance is within the range and limitations of the Steady State Compliance prescribed in IEEE C37.118.1-2014. In this test the magnitude, frequency, and phase offset are constant and fixed for the duration of the test.

The steady state compliance tests compare Total Vector Error (TVE), Frequency Error (FE), and Rate of change of Frequency Error (RFE) with the following tests:

- Signal Frequency Range.
- Voltage and Current Signal Magnitude.
- Phase Angle.
- Harmonic Distortion.
- Out-of-band Interference(Interharmonics).

4.1 Dynamic Tests/Dynamic Compliance Tests

Dynamic tests are intended to show the performance of PMUs under varying magnitude and frequency conditions typical of real operating power systems and to ensure that the PMUs performance is within the range and limitations in IEEE C37.118.1-2014 'Dynamic Compliance'.

The dynamic compliance tests compare TVE, FE and RFE with these tests:

- Amplitude and frequency modulation (and mixed).
- Frequency ramp test.
- Step changes (phase and magnitude).
- Reporting latency.

Figure 5 shows the 6135A calibration system set-up at Power Systems Division of CPRI.

Figure 5. 6135A fluke PMU calibration system.

5. PMU Testing and Results

This section presents the results obtained from steady state and dynamic compliance testing of commercial PMUs from two different vendors.

Before the commencement of testing of PMU's using the Calibrator the following connections are to be ensured:

- All the three phase voltage and current signals from the Calibrator is to be connected to the PMU in the correct sequence.
- Ethernet communications cable from the Calibration System to the PMU.
- GPS signal cable from the Calibration System to the PMU.
- The communication port on the PMU to be turned on and the properties to the required communication standard.
- The nominal frequency, reporting rate, and class i.e., inputs necessary for the calibration procedure are to be inputted.

All the tests reported here are performed at test signal frequency of 50 Hz and the PMU reporting rate of 25 frames per second. Appendix I and Appendix II gives the sample reports of the test results for two typical PMU's. The measurement result gives the (a) steady state results of frequency response, harmonic distortion, out of band interference signal magnitudes (voltage and current) and (b) Dynamic test results for ramp of system frequency, phase modulation and amplitude modulation, Input step change- both amplitude and phase. The latency measurement results are also being provided.

Appendix I reports the results of PMU from manufacturer XXXX. The nominal rating of the PMU is 70 V and current 2 Amps. As seen from the results, the PMU tested has not passed all the tests successfully. The results of twenty five numbers of tests are outside the specified values as per the standards IEEE C37.118.1-2011.

Figures 6 and 7 show the results for a dynamic compliance test during phase modulation for the PMU 'XXXX' (M class) under test. Figures 6 (a-e) shows the TVE, magnitude error, phase error, frequency error and rate of change of frequency error for voltage signal and Figures 7 (a-e) shows the same for current signal.

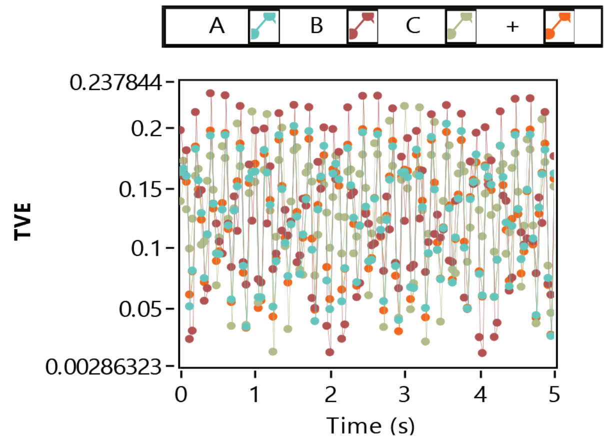

Figure 6(a). Voltage signal – Total Vector Error – Phase Modulation Dynamic test.

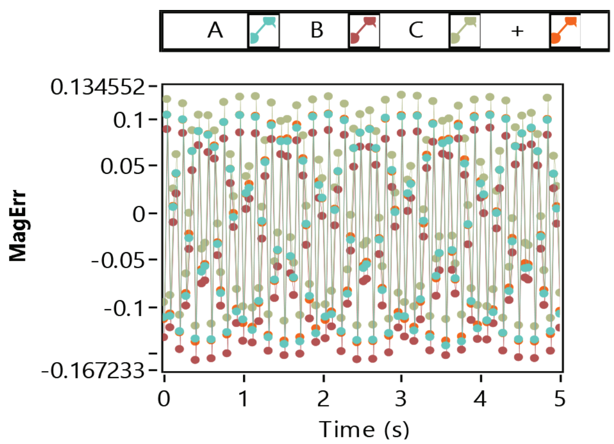

Figure 6(b). Voltage signal – Magnitude Error – Phase Modulation Dynamic test.

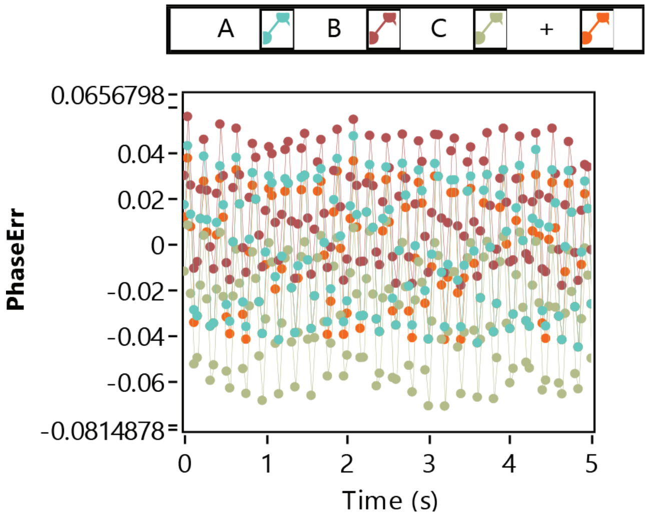

Figure 6(c). Voltage signal – Phase Error – Phase Modulation Dynamic test.

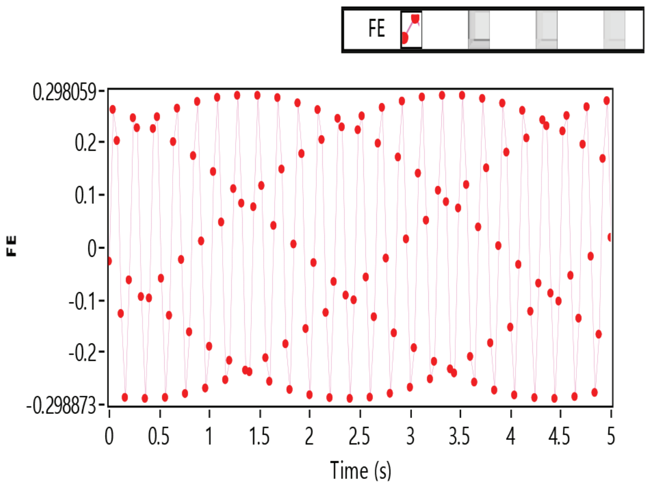

Figure 6(d). Voltage signal – Frequency Error – Phase Modulation Dynamic test.

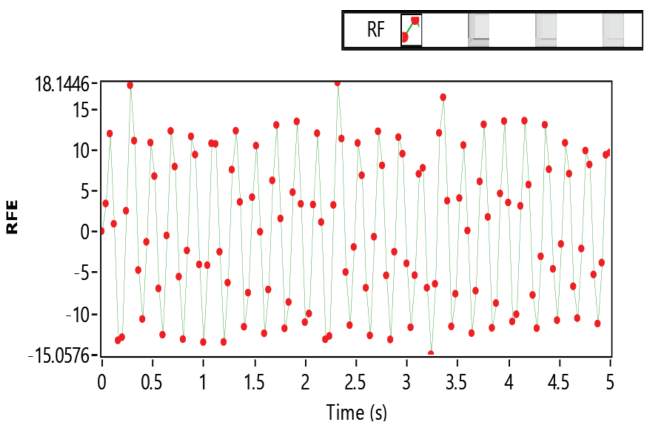

Figure 6(e). Voltage Signal – Rate of change Frequency Error – Frequency Modulation Dynamic test

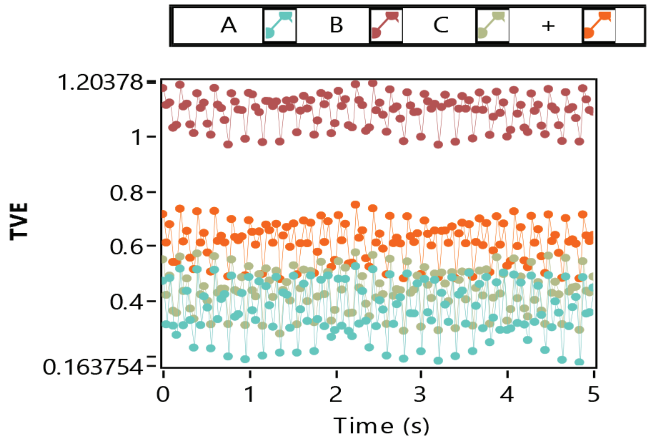

Figure 7(a). Current signal – Total Vector Error – Phase Modulation Dynamic test.

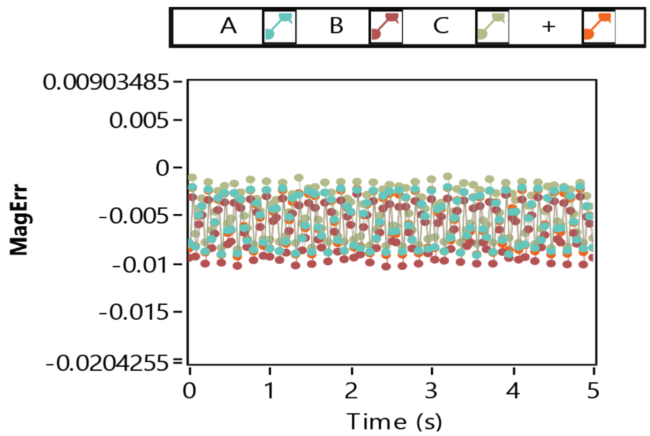

Figure 7(b). Current signal – Magnitude Error – Phase Modulation Dynamic test.

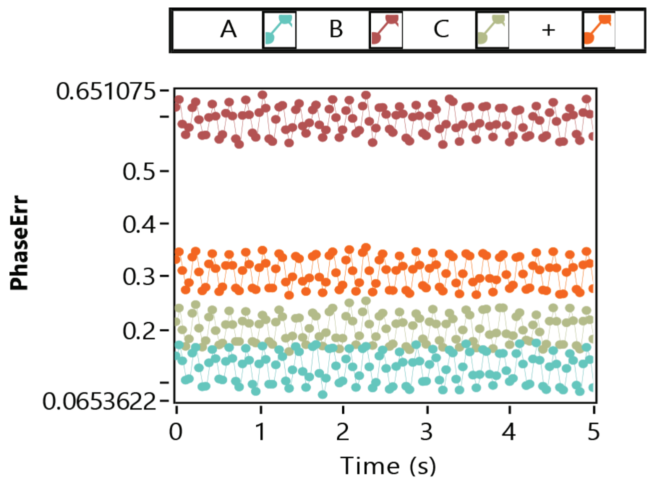

Figure 7(c). Current signal – Phase Error – Phase Modulation Dynamic test.

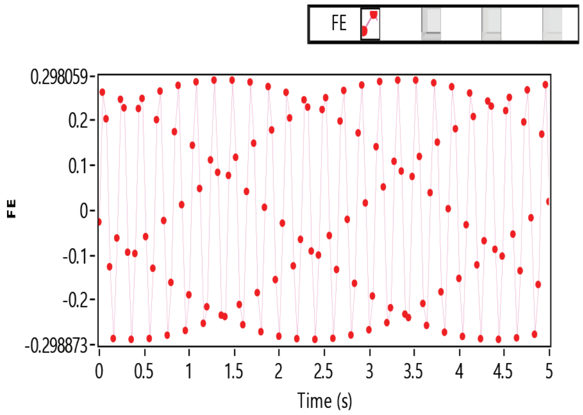

Figure 7(d). Current signal – Frequency Error – Phase Modulation Dynamic test.

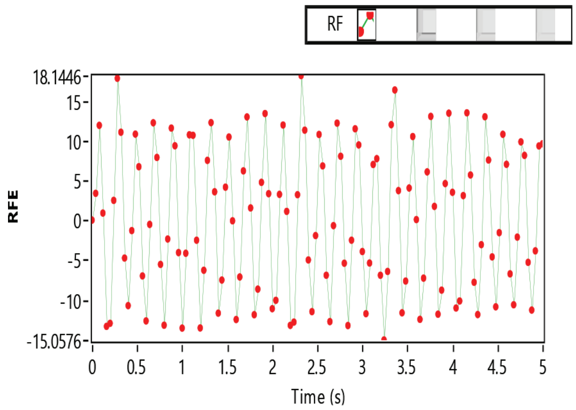

Figure 7(e). Current signal – Rate of change Frequency Error – Frequency Modulation Dynamic test

In this test, the bandwidth of the PMU is investigated. The synchrophasor measurement bandwidth will be determined by sweeping the input with sinusoidal amplitude and phase modulation. It is done by modulating balanced three-phase input signals (voltages and currents) with sinusoidal signals applied to signal amplitudes and phase angles simultaneously in accordance with IEEE C37.118. As seen from the test results and plots the device is non-compliant.

The results of PMU testing from manufacturer YYYY is given in Appendix II. The voltage and current rating of the PMU is 240 V and 5.0 A. The results show that none of the test results are outside the specified values and thus has passed all the tests successfully. Figures 8 (a-e) and Figures 9 (a-e) shows the TVE, magnitude error, phase error, frequency error and rate of change of frequency error for voltage signal and current signals. The device is thus declared to be compliant.

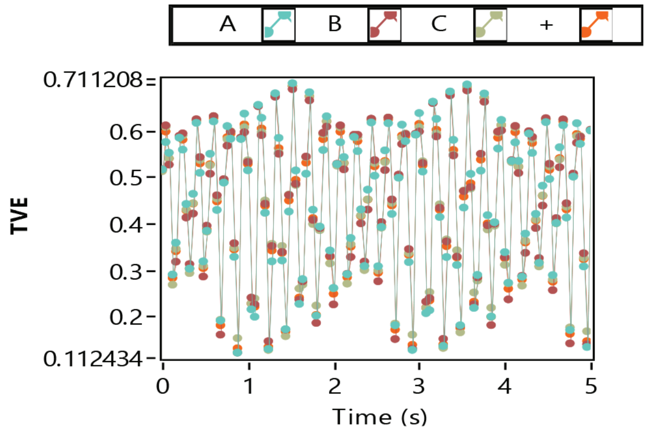

Figure 8(a). Voltage signal – Total Vector Error – Phase Modulation Dynamic test.

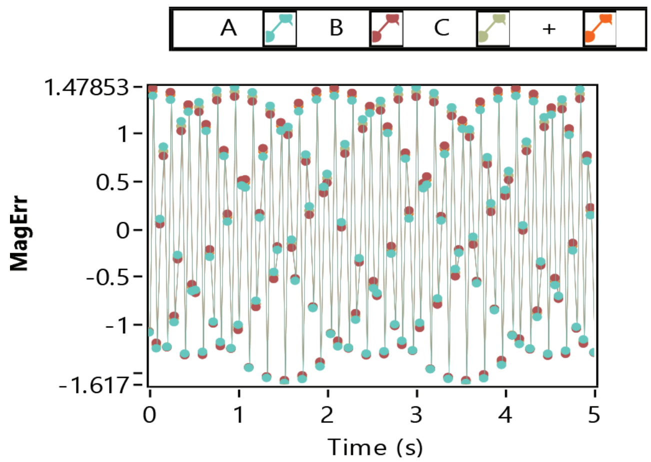

Figure 8(b). Voltage signal – Magnitude Error – Phase Modulation Dynamic test.

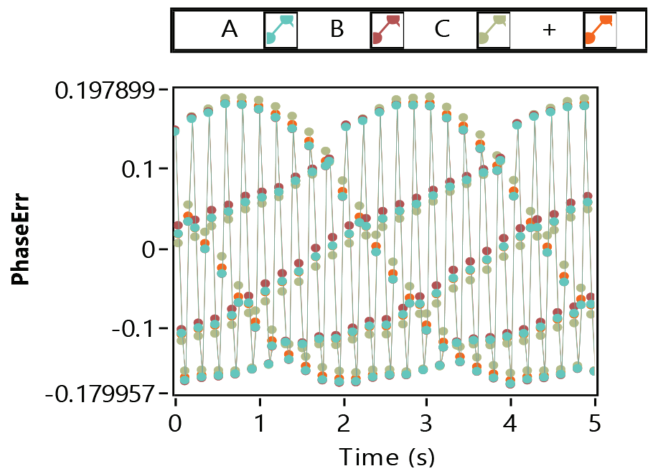

Figure 8(c). Voltage signal – Phase Error – Phase Modulation Dynamic test.

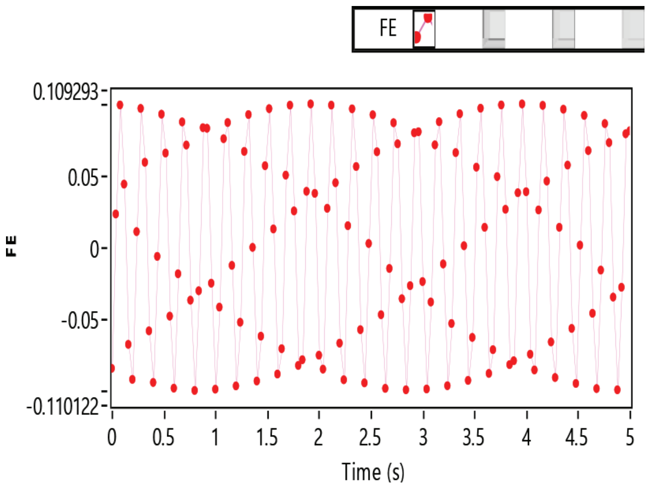

Figure 8(d). Voltage signal – Frequency Error – Phase Modulation Dynamic test.

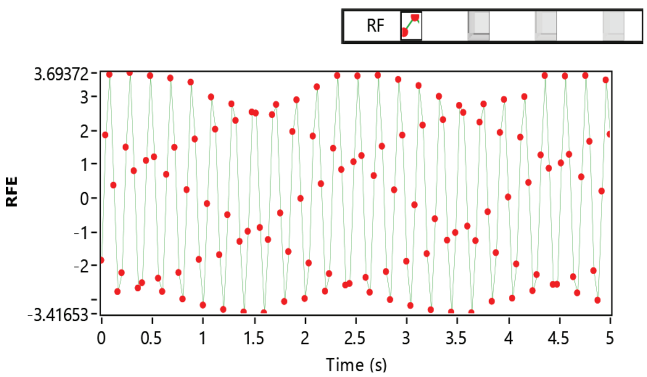

Figure 8(e). Voltage Signal – Rate of change Frequency Error – Frequency Modulation Dynamic test.

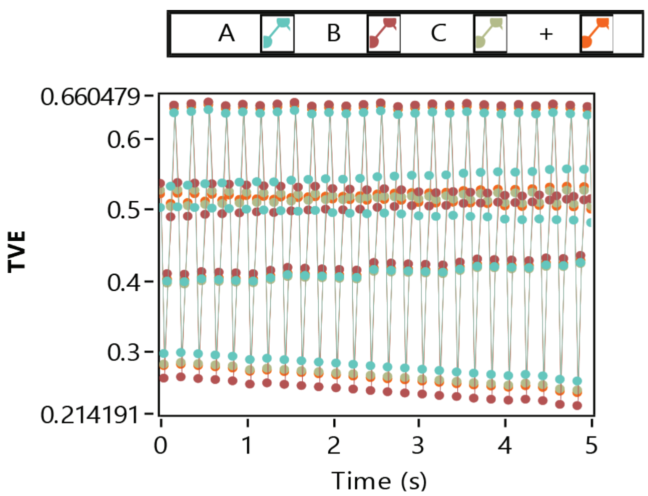

Figure 9(a). Current signal – Total Vector Error – Phase Modulation Dynamic test.

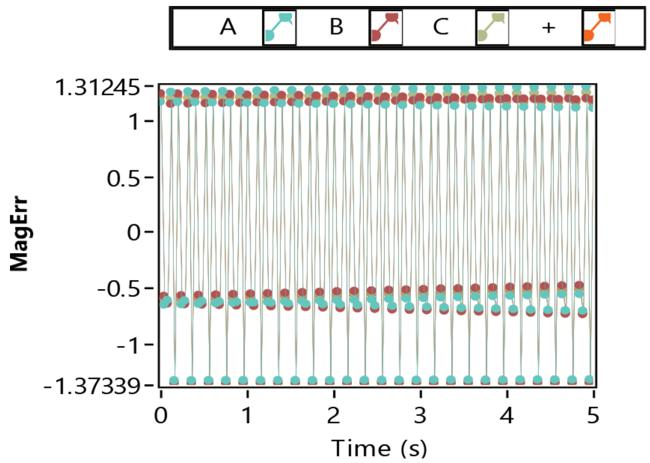

Figure 9(b). Current signal – Magnitude Error – Phase Modulation Dynamic test

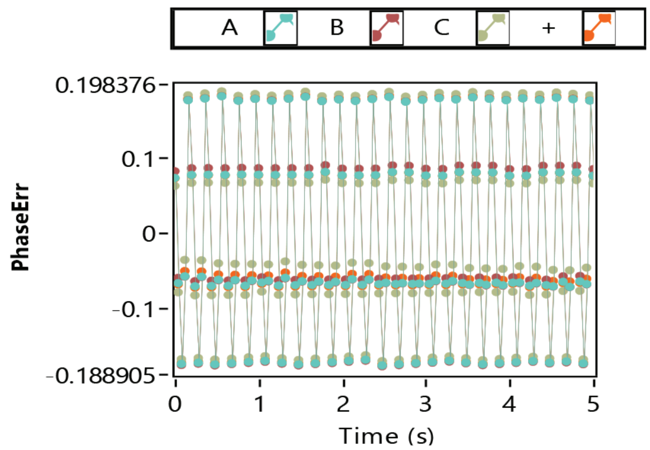

Figure 9(c). Current signal – Phase Error – Phase Modulation Dynamic test

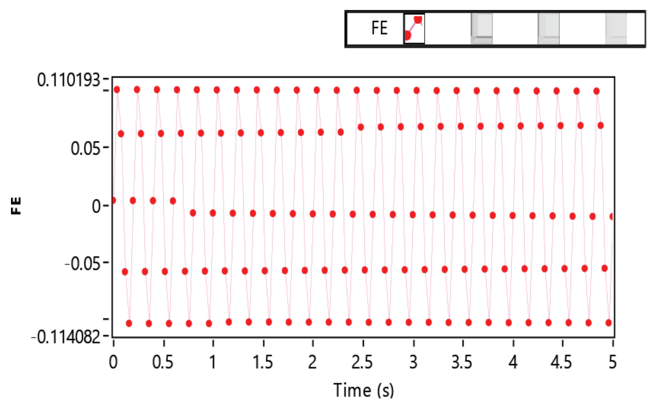

Figure 9(d). Current signal Frequency Error – Phase Modulation Dynamic test

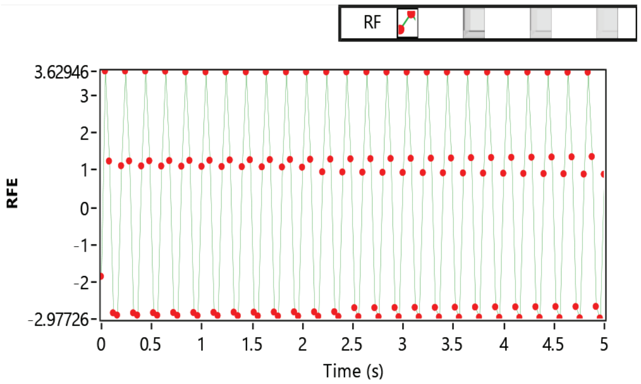

Figure 9(e). Current Signal – Rate of change Frequency Error – Frequency Modulation Dynamic test.

6. Conclusions

With the deployment of PMUs in large numbers, there is an increasing need for testing of such devices.

The accurate and consistent performance of all phasor measurement units is crucial for the reliable performance of the system. Conformance to existing technical standards is of essential value for attaining this particular requirement of the phasor measurement system. Therefore, PMU testing and calibration (phasor magnitude, phase, total vector error and associated uncertainty over all ranges) should be considered as integral part of the implementation of a large scale PMU system.

The PMU calibrators will help utilities ensure the reliability and accuracy of PMUs and seamless interoperability among different vendors. Overcoming this hurdle should encourage utilities to invest more confidently in PMUs and speed up the implementation of 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.

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Appendix

TEST RESULTS

UUT Identifier:
UUT Manufacturer: UUT Class:
Nominal Frequency: Reporting Rate: Nominal Voltage: Nominal Current: Settling Period:

Measurement Equipment Used

dev XXXX M
50Hz
25 Reports per second
70.0V
2.0A
1.0 seconds

Fluke 6135A Three Phase Electrical Standard
Symmetricom XL-GPS Receiver
6105A/PMU Phasor Measurement Unit Calibrator

Report Summary Total number of measurements:	292
Number of Passed measurements:	247
Number of measurements outside test specification:	25
Number of incomplete measurements:	24

Measurement status indicators:

F Measurement outside test specification
I Measurement incomplete

Measurement Results

Test: Steady State - Frequency Response

Signal Frequency Range tests apply a series of steady state input signals at 0.1Hz increments.

	Voltage	Voltage	Voltage	Voltage	Current	Current	Current	Current	**Limit**
	Phase A	PhaseB	Phase C	Pos Seq	Phase A	Phase B	Phase C	Pos Seq	
TVE	0.7984	0.8291	0.7875	0.751	1.098 F	1.565 F	1.108 F	1.172 F	**1**
Fe	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.007	**0.005**
RFe	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.04	**0.1**

Test: Steady State - Harmonic Distortion (single harmonic)

Harmonic Distortion tests apply a series of steady state input signals at nominal frequency with the addition of a single harmonic from 2nd harmonic through 50th harmonic. Harmonic amplitude is 10% of nominal amplitude for M class PMUs and 1% for P class.

	Voltage	Voltage	Voltage	Voltage	Current	Current	Current	Current	**Limit**
	Phase A	PhaseB	Phase C	Pos Seq	Phase A	Phase B	Phase C	Pos Seq	
TVE	0.8638	0.675	0.5115	0.4253	0.3698	1.084 F	0.4142	0.5767	**1**
Fe	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	**0.025**
RFe	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	**Inf**

Test: Steady State - Out-of-band interference (interharmonics)

Out-of-band interference (interharmonic) tests apply a series of steady state input signals at nominal and off-nominal frequency with the addition of a single interharmonic signal.

	Voltage	Voltage	Voltage	Voltage	Current	Current	Current	Current	Limit
	Phase A	PhaseB	Phase C	Pos Seq	Phase A	Phase B	Phase C	Pos Seq	
TVE	0.4577	0.4826	0.4392	0.411	0.7395	1.326 F	0.7547	0.877	1.3
Fe	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.01
RFe	1.86	1.86	1.86	1.86	1.86	1.86	1.86	1.86	Inf

Test: Steady State - Signal Magnitude (voltage and current)

Signal maginitude tests apply a series steady state input signals at nominal frequency with varied magnitude.

	Voltage	Voltage	Voltage	Voltage	Current	Current	Current	Current	**Limit**
	Phase A	PhaseB	Phase C	Pos Seq	Phase A	Phase B	Phase C	Pos Seq	
TVE	0.1255	0.1316	0.1254	0.1191	0.844	1.446 F	0.5648	0.7469	**1**
Fe	0	0	0	0	0	0	0	0	**Inf**
RFe	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	**Inf**

Test: Dynamic - Ramp of system frequency

Two tests where the input frequency is dynamically ramped (linear chirp). The two tests include a positive frequency slope ramp and a negative frequency slope ramp. The included frequency range for the test was 45.32Hz to 54.68Hz.

	Voltage	Voltage	Voltage	Voltage	Current	Current	Current	Current	Limit
	Phase A	PhaseB	Phase C	Pos Seq	Phase A	Phase B	Phase C	Pos Seq	
TVE	0.6589	0.6785	0.6355	0.5998	0.9132	1.527 F	0.9329	1.067 F	1
Fe	0.02119 F	0.02119 F	0.02119 F	0.02119 F	0.02119 F	0.02119 F	0.02119 F	0.02119 F	0.01
RFe	0.04003	0.04003	0.04003	0.04003	0.04003	0.04003	0.04003	0.04003	0.2

Test: Dynamic - Measurement Bandwidth (Phase Modulation)

A series of tests where input signal phase is modulated over a range of modulation frequencies. Modulation index is specified dependent on PMU class.

	Voltage	Voltage	Voltage	Voltage	Current	Current	Current	Current	Limit
	Phase A	PhaseB	Phase C	Pos Seq	Phase A	Phase B	Phase C	Pos Seq	
TVE	0.2025	0.2278	0.2172	0.198	0.5253	1.194	0.5756	1.7498	3
Fe	0.2966	0.2966	0.2966	0.2966	0.2966	0.2966	0.2966	0.2966	0.3
RFe	18.13 F	18.13 F	18.13 F	18.13 F	18.13 F	18.13 F	18.13 F	18.13 F	14

Test: Dynamic - Measurement Bandwidth (Amplitude Modulation)

A series of tests where input signal phase is modulated over a range of modulation frequencies. Modulation index is dependent on PMU class.

	Voltage	Voltage	Voltage	Voltage	Current	Current	Current	Current	**Limit**
	Phase A	PhaseB	Phase C	Pos Seq	Phase A	Phase B	Phase C	Pos Seq	
TVE	0.2876	0.3195	0.2942	0.29	0.5927	1.22	0.641	0.788	**3**
Fe	0	0	0	0	0	0	0	0	**0.3**
RFe	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	**14**

Test: Dynamic - Input Step Change (Phase)

Two dynamic tests made up of 10 sub-tests each. Each sub test steps the phase. After the sub tests are completed, the data is indexed and overlaid to create an equivalent time sampling result with 10 times the sampling resolution of a single report.

	Voltage Phase A	Voltage PhaseB	Voltage Phase C	Voltage Pos Seq	Current Phase A	Current Phase B	Current Phase C	Current Pos Seq	Limit
PhasorRespTime	0.132	0.14	0.136	0.136	0.132	-3.6E+09	0.112	0.116	0.28
PhasorDelayTime	0.004	0	0.000932	0.004	0.004	0	0.000955	0.004	0.01
PhaseOvershoot	0.3947	0.4871	0.4807	0.4068	0.3969	0.4904	0.4813	0.4091	10
FreqRespTime	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.56
ROCOFRespTime	0	0	0	0	0	0	0	0	0.56
FreqOverShoot	0.446	0.446	0.446	0.446	0.446	0.446	0.446	0.446	Inf
ROCOFOvershoot	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Inf
AmplOvershoot	0	0	0	0	0	0	0	0	Inf

Test: Dynamic Input Step Change (amplitude)

Two dynamic tests made up of 10 sub-tests each. Each sub test steps the amplitude. After the sub tests are completed, the data is indexed and overlaid to create an equivalent time sampling result with 10 times the sampling resolution of a single report.

	Voltage Phase A	Voltage PhaseB	Voltage Phase C	Voltage Pos Seq	Current Phase A	Current Phase B	Current Phase C	Current Pos Seq	Limit
PhasorRespTime	0.052	0.052	0.052	0.052	0.096	-3.6E+09	0.092	0.1	0.28
PhasorDelayTime	0.000318	0.001485	-0.00126	0.000175	0.000372	0.001561	-0.00131	0.00022	0.01
PhaseOvershoot	0	0	0	0	0	0	0	0	Inf
FreqRespTime	0	0	0	0	0	0	0	0	0.56
ROCOFRespTime	0	0	0	0	0	0	0	0	0.56
FreqOverShoot	0	0	0	0	0	0	0	0	Inf
ROCOFOvershoot	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	Inf
AmplOvershoot	6.75	6.896	6.915	6.853	0.1988	0.2005	0.1995	0.1953	10

Test: Measurement Reporting Latency

Measurement Reporting Latency is determined using at least 1000 consecutive messages. The measurement is the time interval between the reported time stamp within the data and the time when the data becomes available at the PMU output.

	Latency (ms)	Limit (ms)
Maximum	166.733	280
Mnimum	164.179	