

North American Synchrophasor Initiative

Report of Task Force on Testing and Certification

Final Report

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Executive Summary

This Task Force (TF) is formed by the management team of the North American Synchrophasor Initiative (NASPI) with the goal of assessing need for and status of the testing and certification process for synchrophasor technology. The TF membership was selected to cover different synchrophasor technology stakeholder groups. The following are the TF findings:

- The scope of synchrophasor technology reaches well beyond phasor measurement units (PMUs), so it would take a long time to cover the process for the entire system. It is recommended that the initial efforts should primarily focus on establishing a testing and certification process solely for PMUs (as defined in Institute of Electrical and Electronics Engineers (IEEE) Standard C37.118.1-2011 and future amendments).
- Current practice in verifying the conformance of synchrophasor technology, particularly PMUs, to existing standards is not consistent and does not resemble the recommendations in widely accepted industry practice outlined in standard International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 17025 and ISO/IEC Guide 65 (recently revised as ISO 17065:2012).
- The guidance defined by the Testing and Certification Committee (TCC) of the Smart Grid Interoperability Panel (SGIP), summarized in this report, is highly recommended for the synchrophasor technology stakeholders to follow. Since the TCC offers assistance in initiating the testing and certification process, PMU stakeholders should take advantage of this opportunity.
- The ISO standards mentioned assume that there is an industry-driven process for certification of the testing labs and test plans, as well as an organizational method for managing the certification process. Neither of the two requirements is currently in place for PMUs. Efforts are underway to fulfill these requirements as discussed in this report.
- It is recognized that synchrophasor technology is undergoing rapid changes and that both a PMU standard (IEEE Std. C37.118.1) and products will be undergoing changes in the near future; hence the testing and certification process is needed to make sure the new and existing products can be verified against the revised standard requirements.
- The need for testing and certification was revealed by published test results that existing products do not meet all the requirements specified in the existing standard. This creates a level of uncertainty as to how such products will perform when used for given applications. The testing and certification process has to provide comprehensive, multi-vendor results to allow users to assess PMU performance impact on applications.
- To facilitate the process of certification of test laboratories and test plans, the National Institute of Standards and Technology (NIST) has initiated an effort described as PMU testing Inter-Laboratory Comparison (ILC) or “round robin.” While this is not meant to be a certification process for test laboratories, the intent is to identify issues causing different results for the same tests performed by different laboratories.
- IEEE has initiated a PMU certification procedure for test laboratories but all the details are not yet outlined. For IEEE to have a successful procedure and process in place, it created a Steering Committee to provide feedback from all the

stakeholder groups. IEEE endeavors to adhere to the TCC recommendations for this process to succeed.

- To have a successful development and implementation of the testing and certification process, stakeholders should agree on clearly outlined processes and procedures, provide training in performing the same, and maintain up-to-date databases and materials for all users.

1. Introduction

This section gives an overview of the status of synchrophasor technology, synchrophasor deployment, and the testing and certification process. It ends with a brief description of the scope of the task force (TF) assignment and the goals of this report.

1.1 Synchrophasor Deployment Issues

The concept of synchrophasor measurements was developed over 30 years ago. At that time, large-scale commercialization and deployment was prevented by limited communication capabilities at reasonable costs between substations and utility control centers, as well as costs of time synchronization infrastructure. Due to lack of reliable synchrophasor data from wide-area interconnections, grid reliability applications using synchrophasor data had not matured. A few utilities in the Western Electricity Coordinating Council (WECC) were early adopters, motivated mainly by the inter-area oscillation problems experienced in the interconnection. There were not many early adopters in the Eastern Interconnection. However, the release of the August 14, 2003, blackout report indicated that synchrophasor technology would have been extremely useful for on-line and subsequent analysis, and potentially could have made operators aware of situations over a wide area of the interconnection and possibly averted the blackout. After the blackout, significant interest developed in the east and this interest expanded to the west and ultimately led to the establishment of the North American Synchrophasor Initiative (NASPI). NASPI is a collaborative effort between the U.S. Department of Energy, the North American Electric Reliability Corporation (NERC), and North American electric utilities, vendors, consultants, federal and private researchers and academics. NASPI management initiated a task force to produce this report.

Approximately 150 networked phasor measurement units (PMU)s were deployed across the United States by late 2009. In October, 2009 the U.S. Department of Energy announced a \$3.4 billion investment under the American Recovery and Reinvestment Act (ARRA) to spur transition to Smart Energy Grid. This incentive also included synchrophasor deployments for improved monitoring of grid dynamics over a wide area. As part of this deployment grant, synchrophasors in more than 850 substations are being deployed, along with the necessary infrastructure to collect data and develop reliability applications using this data. In addition to large-scale deployment of the synchrophasor technology in the United States, China, India, countries in the European grid, Russia, Australia, Brazil, and Indonesia have initiated projects focused on wide-area monitoring using synchrophasor technology.

As mentioned above, thousands of synchrophasor measuring devices were installed or are in the process of deployment worldwide. The majority of these systems are thought to adhere to the Institute of Electrical and Electronics Engineers (IEEE) Standard C37.118-2005. A few older installations followed IEEE 1344 or other proprietary protocols. The 2005 standard did not address dynamic performance, frequency, or rate of change of frequency (ROCOF) requirements for synchrophasor measurements. In 2011, IEEE adopted Standard C37.118.1-2011, which addresses these requirements. Also, at the time of this writing, IEEE is in the process of adopting an amendment to C37.118.1-2011. IEEE also separated the data transmission requirements from the PMU performance

requirements by developing IEEE Std. C37.118.2-2011. With the large installed base using the 2005 standard's data transmission protocol, the new C37.118.2 data transmission standard maintained backward compatibility to provide continued support with some improvements over the 2005 version. To maintain backward compatibility, a number of desirable features and enhancements were not included.

It is important to the end-users of the data that devices available from various vendors be interoperable. This means that not only the protocols and formats must be identical, but also that synchrophasor, frequency, and ROCOF measurements from various devices must be within measurement accuracy limits over the expected ranges of these measurements. NIST and several university laboratories are equipped to test several synchrophasor measurement devices for performance compared with that required in the standards. Some tests published recently indicated that none of the PMU devices sold on the North American market met all the requirements of Standard C37.118.1-2011. However, since there is no verification program for the testing entities, it is likely that each test setup and process may not provide identical results.

1.2 End-to-End System Developments Going Forward

The end-to-end data flow in a typical synchrophasor system solution is shown in Figure 1. From the figure it is obvious that wide-area measurement, protection, and control (WAMPAC) solutions consist of many diverse parts: phasor measurement intelligent electronic devices (IEDs) such as phasor measurement units (PMUs), digital protective relays (DPRs), digital fault recorders (DFRs) etc., as well as phasor data concentrators (PDCs), and many communication, data management and visualization servers acting as gateways, data historians, and data analytics engines. To make sure the system meets future interoperability requirements, one must anticipate how the future expansion of the system may unfold. However, the key component of the system is the phasor measurement suite of products.

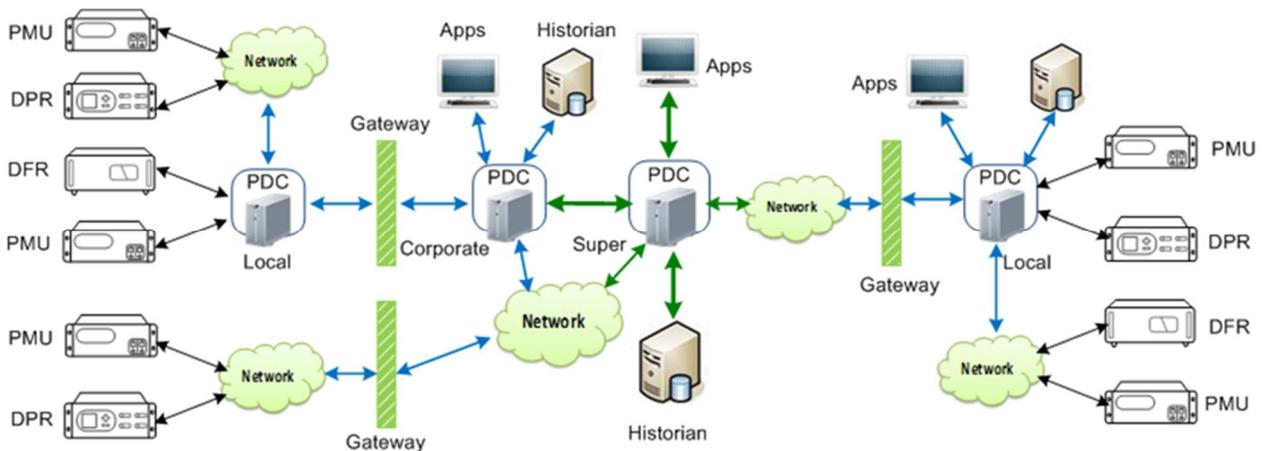


Figure 1. Typical End-to-End Synchrophasor Wide-Area Measurement, Protection and Control System and its Components

This report is focused on phasor measurement units (PMUs) and the testing and certification processes for such products. It is, however, well recognized that certification

and testing processes may eventually have to be developed for all parts of the system solution.

1.3 Scope of the TF Report

The scope of this report comprises the following:

- Introduce a wider audience to the latest activities and recommendations of various organizations regarding the testing and certification process.
- Give a brief assessment of the status of synchrophasor technology, current standardization activities, and the testing and certification process.
- Propose immediate action items required to establish a testing and certification process for stand-alone PMUs.
- Define a long-term roadmap for the testing and certification process that will eventually include the system aspect of synchrophasor technology end-to-end solutions.

2. The Testing and Certification Process

Current testing and certification programs for Smart Grid systems and devices are varied in their processes, complexity and rigor. This was an early observation of the Smart Grid Interoperability Panel (SGIP) Testing and Certification Committee (SGTCC). The SGTCC was created as a standing committee within the SGIP to take responsibility for establishing a framework for testing and certification to be used in enabling standards-based interoperability of Smart Grid systems and devices. It is a unique group comprising testing experts across many stakeholder areas including utilities, test laboratories, manufacturers and test program operators. Many of the SGTCC experts have extensive experience in developing test programs in multiple industries; they work together to help to bring lessons learned and best practices to Smart Grid programs as they emerge.

2.1 Testing and Certification Framework

The SGTCC developed and issued an Interoperability Process Reference Manual (IPRM) as a key foundational element of the SGIP Testing and Certification Framework. The IPRM introduces key testing and certification processes necessary to achieve interoperability in a consistent manner over time. It enables the adoption of measurable certification and testing policies and procedures across Smart Grid products. The IPRM utilizes standards and the experience and expertise of SGTCC participants in conformance, interoperability, and cybersecurity testing.

The IPRM also requires use of the widely accepted International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 17025 and ISO/IEC Guide 65 (recently revised as ISO 17065:2012) international standards for testing-laboratory and certification-body management systems. The ISO/IEC testing and certification standards provide a solid foundation for the development and operation of high quality testing and certification programs. The SGTCC also recognized that additional technical requirements and best practices are necessary to help assure test program technical depth and sufficiency in meeting end-user expectations for interoperability and cybersecurity. These additional recommendations were incorporated into the IPRM.

2.2 Testing and Certification Program Operators

The IPRM is intended for use by organizations whose functions are to promote and facilitate the introduction of interoperable products to the marketplace based on Smart Grid standards. These organizations are referred to by the SGTCC as Interoperability Testing and Certification Authorities (ITCA).

An ITCA is a program management organization providing oversight for testing and certification activities associated with one or more standards or specifications. The ITCA takes responsibility to make sure that interoperable products within the scope of the specific ITCA program are brought to market. The ITCA coordinates the participation of certification bodies and test labs for its program.

An early finding of the SGTCC was that products that had an associated ITCA engaged in testing and certification of products to a standard were more rapidly implemented and adopted by the marketplace.

The SGTCC has established the following required practices for ITCAs, certification bodies and test laboratories:

- Certification bodies shall be accredited to ISO Guide 65 (recently revised as ISO 17065:2012), *General Requirements for Bodies Operating Product Certification Systems*.
- Test laboratories shall be accredited to ISO 17025, *General Requirements for the Competence of Testing and Calibration Laboratories*.
- The ITCA shall have an agreement with an accrediting organization(s) to make sure that certification body and test laboratory accreditation is being performed in accordance with the ITCA program scheme.
- An ITCA shall have a strong relationship with the standards-setting organization (SSO) associated with the standard for the purpose of feedback toward standard improvement and clarification where there may be ambiguities. An example of an SSO would be the IEEE working group that authored the standard.

The requirements for adherence of ITCAs to these internationally recognized industry standards are consistent with the practices exhibited in other industry programs engaged in testing and certification activities related to critical infrastructures.

The SGTCC believes that implementation of the IPRM will lead to lower deployment costs of Smart Grid systems and devices and enhanced product quality with respect to interoperability and conformance, which will ultimately provide increased confidence to the buyer through meaningful certification programs and result in end-user customer satisfaction.

2.3 SGIP Support for Emerging ITCA

It is envisioned that over time, many of the standards included in the SGIP Catalog of Standards will have associated testing and/or certification services overseen by an ITCA. New ITCAs are just beginning to emerge and the SGTCC has noted a need to provide guidance to these organizations to help them develop and implement programs that align with the expectations cited in the IPRM. The SGTCC developed and issued the “ITCA Development Guide and FAQ” document in November 2012. It is intended to provide a concise guide to step new ITCAs through the implementation of IPRM recommendations.

In setting up and operating an ITCA, a series of activities and responsibilities are addressed specifically or implied in the IPRM, most of them enumerated in a separate section. The ITCA Development Guide is intended to organize the IPRM explicit and implicit requirements and suggested best practices for an ITCA into a roadmap to follow in launching its program.

2.4 Testing Considerations for the SGIP Catalog of Standards

The SGIP has developed a Catalog of Standards (CoS). The CoS is a compendium of standards and practices considered to be relevant for the development and deployment of a robust and interoperable Smart Grid. The CoS may contain multiple entries that may

accomplish the same goals and are functionally equivalent; similarly a single CoS entry may contain optional elements that need not be included in all implementations. In general, compliance with a standard does not guarantee interoperability due to the above reasons. Though standards facilitate interoperability, they rarely, if ever, cover all levels of agreement and configuration required in practice.

As a part of its work program, the SGIP is defining a testing and certification program framework that may be applied to the equipment, devices, and systems built to the standards listed in the Catalog and that, if applied, will substantiate that implementations claiming compliance with the respective standards are also interoperable. Where test profiles have been defined and testing organizations identified for a particular standard, this will be indicated in the Catalog entry. The TF believes that standards related to synchrophasor technology should become part of the CoS; hence a motivation to meet the requirements for such inclusion, which includes a defined testing and certification process and procedure.

The SGTCC has developed processes for the purpose of reviewing standards proposed for inclusion in the SGIP CoS, from the perspective of the standard’s maturity with respect to testing and certification issues. The SGTCC review process will take place in parallel with reviews performed by other SGIP standing committees such as architecture and cybersecurity. The end result of an SGTCC CoS review is a detailed analysis summary based on consistent criteria and metrics that may be applied across any standard under review. The SGTCC does not intend its reviews to be used as a single qualifier to determine whether a standard should or should not be included in the CoS. Rather, the analysis summary will be provided to the SGIP Program Management Office (PMO), and the PMO will review and post the SGTCC summary, along with those provided by the other standing committees, to present a comprehensive view and recommendation to the SGIP Board of Governors to vote on final disposition of the standard’s inclusion (or not) in the CoS. Synchrophasor technology standards should benefit from being exposed to the mentioned scrutiny.

2.5 Testing Laboratory Equipment and Procedures

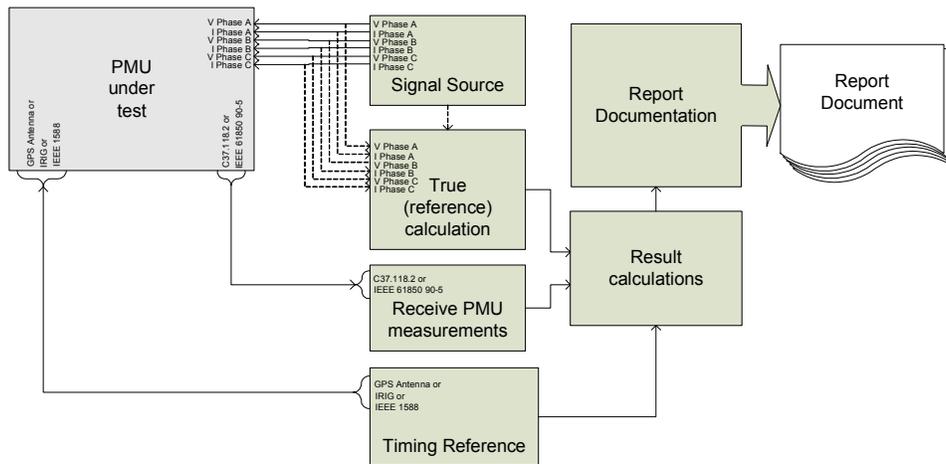


Figure 2. Typical Calibration Equipment Setup for PMU Testing and Calibration

As illustrated in Figure 2 the following functions are required for PMU calibration devices:

1. Provide timing reference to the PMU and to the calibrator itself.
2. Provide voltage and current input signals (signal source(s))
3. Receive measurements from the PMU under test (receiver)
4. Compare phasor, frequency and ROCOF measurements from the PMU to a “true” (reference) phasor, frequency and ROCOF representing the signal source input to the PMU.
5. Perform calculations for total vector error (TVE), frequency error (FE) and rate of change of frequency error (RFE), and additional calculations for the dynamic step test results.
6. Provide test result documentation.

A detailed description of the equipment needed in a PMU test laboratory and uncertainty requirements for test laboratory equipment, as well as some of the test procedures, are in Annex A: Test Lab Equipment and Procedures.

3. Status of Synchrophasor Technology Testing and Certification

This section surveys the status of related standards, as well as status of the ongoing testing and certification efforts. The testing efforts need to define a *procedure* for testing the synchrophasor products, as well as the certification *process* that leads to issuing certificates.

3.1 History of PMU Standards Development

Early synchrophasor experiments of the 1980s and 1990s led to IEEE Std. 1399-1995, which described the requirements for making a synchrophasor measurement and specifying a message format for transmitting the measurements. Annex B of the standard briefly discussed measurement accuracy and some performance factors to consider. No performance limits were specified and testing of the message format was not addressed.

Between 1995 and 2005, several papers were published on phasor measurement *algorithms* to improve performance under dynamic conditions. There were additional papers on *applications* of synchrophasor measurements; however, few papers addressed the topic of *testing* PMUs. In 2004, Arun Phadke et al. published an IEEE conference paper on comparative testing of PMUs.^{1,2} IEEE published C37.118-2005, which standardized the concept of TVE and set some normative limits on the steady-state performance of PMUs. The standard also defined compliance verification *requirements*. Annex G suggested some “benchmark tests” consisting of steps in magnitude, phase and frequency. No real discussion of message protocol testing was made.

Between 2005 and 2013, numerous papers on PMU testing were published. Many of these discussed testing under dynamic signal conditions in addition to steady-state conditions. In 2008, NASPI Phasor Specification and Technical Standards (PSTT) workgroup published the PMU Testing Guide, which has since been retired in favor of IEEE Std. C37.118.1 and IEEE Std. C37.242-2013. C37.242-2013 updates and combines several NASPI guides.

IEEE Std. C37.118.1-2011, *Standard for Synchrophasor Measurements for Power Systems*, added dynamic test limits to TVE and added limits for all tests of FE and RFE. Annex E of the standard details TVE and discusses PMU performance testing. An amendment to C37.118.1 has been adopted by IEEE at the time of this writing.

IEEE Std. C37.118.2, *Standard for Synchrophasor Data Transfer for Power Systems* added a third configuration message type to the message format and revised the use of some former security bits to include time quality meaning. There is no discussion of message format testing. One reason the standard was split into two parts was to aid in PMU standardization by the IEC, which requires separate standards for electrical

¹ A. Phadke, M. Ingram, V. Centeno, J. Depablos, “Comparative testing of synchronized phasor measurement units,” IEEE PES General Meeting, June 2004.

² J. Ren, M. Kezunovic, Y. Guan, “Verifying Interoperability and Application Performance of PMUs and PMU-enabled IEDs,” IEEE P&E Society General Meeting, San Diego, USA, July 2012.

performance and data transmission. Another reason was to transport synchrophasor data over the IEC 61850 protocol. An IEC Technical Report, IEC/TR 61850-90-5, describes the use of IEC 61805 to transmit synchrophasor data according to C37.118. (The report title does not mention whether this is -2005 or .2-2011).

3.2 Status of Synchrophasor Standards

This section provides a review of the synchrophasor solution-related standards as of this date (October 2013). These standards fall into four categories: approved, in the approval process, under development, and other related standards/guidelines.

Approved standards are as follows:

- IEEE 37.111-1999, *IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems*
- IEEE 37.118-2005, *Standard for Synchrophasors for Power Systems*
- IEEE 37.232-2007, *Recommended Practice for Naming Time Sequence Data Files*
- IEEE 37.239-2010, *Standard for Common Format for Event Data Exchange (COMFEDE) for Power Systems”*
- IEEE C37.238-2011, *Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications*
- NERC CIP 2-9, Version #5
- IEC 61850 (90-5), 2012 “PMU Logical Node,” an implementation report, not a standard
- IEEE C37.118.1-2011, *Standard for Synchrophasor Measurements for Power Systems*
- IEEE C37.118.2-2011, *Synchrophasor Data Transfer for Power Systems*
- IEEE C37.244-2013, *Guide for Phasor Data Concentrator Requirements for Power System Protection, Control and Monitoring*
- IEEE 37.242-2013, *Guide for Synchronization, Calibration, Testing and Installation of Phasor Measurement Units for Power System Protection and Control*

Standards in the approval process are as follows:

- IEC version of COMTRADE (IEC 60255-24, Ed 2)
- IEEE PC37.118.1a (proposed) “Amendment 1 to C37.118.1-2011: Modification of Selected Performance Requirements”

Standards under development are as follows:

- PC 37.240, “Standard for Cyber Security Requirements for Substation Automation, Protection and Control Systems”

Other related standards/guidelines are as follows:

- IEC 61850 *Substation Automation*
- IEC 61970 *Common Information Model*
- National Institute of Standards and Technology Interagency Report (NISTIR) 7628, a guideline, not a standard
- IEC 62351-6: security for 61850
- IEC 62351: other security considerations
- IEEE 1815-2010 *DNP Standard for Electric Power System Communications*
- IETF RFC 6272 *Internet Protocol Standards for the Smart Grid*

While this review is not exhaustive, the list already contains over 20 standards and guidelines related to synchrophasor implementation.

3.3 Status of PMU Testing and Certification

Several labs have been testing PMUs and finding that no PMU currently available for purchase meets the requirements of IEEE C37.118.1. NIST is in the process of drafting a 2013 survey of PMU performance and has provided an early draft copy of the survey to the IEEE PMU working group membership. A task force within the working group has concluded that an amendment to the standard is needed because some of the test limits could not be reached by PMUs available on the market. An amendment proposal is being adopted by the IEEE Power Systems Relaying Committee (PSRC) at the time of this writing.

However, even after the standard has been amended as proposed, the PMUs surveyed so far may still not meet the new requirements. In such cases, PMUs will need to be revised to meet the amended 2011 requirements and subsequently retested.

Test systems also need to be revised. The proposed amendment to the PMU standard changes some of the test limits and clarifies some of the test signal requirements.

Currently, there is no program to certify PMUs or PMU test systems. Descriptions of the work in progress to create PMU test and certification programs follow.

3.4 Proposed Testing and Certification Efforts by IEEE ICAP

The SGIP IPRM defines the requirements for an ITCA to create a Test Suite Specification (TSS). This document specifies the specific test methodologies to be followed and clarifies any ambiguities that may be in the standard to which a device is being tested. It is the responsibility of the ITCA to work closely with the SSO to validate the TSS and make sure the ambiguities have been clarified correctly.

An effort is currently underway in the IEEE Conformity Assessment Program (ICAP) Synchrophasor Conformity Assessment Steering Committee (SCASC) to develop a TSS for PMU measurement performance testing and certification in accordance with the SGIP and with IEEE Std. C37.118.1. ICAP also announced recently that it will act as an ITCA for PMU testing and certification.

There is no known effort underway to develop test and certification plans for PMU data transfer or any other related synchrophasor standards.

4. NIST Activities and PMU Calibrator Development

The NIST SynchroMetrology Laboratory is organized under the Physical Measurement Laboratory (PML) division in Gaithersburg, Maryland. PMU calibration has been a responsibility of this laboratory since about 2005. While the SynchroMetrology Lab has a five-year plan of projects, it should be understood that the plan is subject to change at any time and without notice. The plan is designed so that short-term projects have greater detail and longer-term projects are more general and subject to refinement over time. Key projects of the five-year plan, as of Oct 2013, are described below in priority order.

4.1 2013 Survey of PMU Performance

- Survey of nine PMU end-users to determine whether recommended application limits for FE and RFE can be determined.
- Measure and report on performance of PMUs currently shipping and under development under each of the C37.118.1 required test inputs. All PMU vendors are invited to participate.
- Test the C37.118.1 Annex C Signal processing model and the proposed amendment to the model against the C37.118.1 requirements with both simulated and actual test signals.

Objective: help ensure the quality of PMU standards and future PMU development.

Desired result: report to SSOs.

4.2 PMU Message Latency Testing System Development

Objective: advance PMU testing in areas not known to be covered by other organizations.

Desired result: run the test on various PMUs and determine their level of compliance to the measurement latency limit set by IEEE Std. C37.118.1.

4.3 PMU Testing Inter-Laboratory Comparison (ILC)

This should not be confused with laboratory assessment or certification of test laboratories. This ILC is a “first look” at how laboratory results compare to each other when a subset of the PMU tests required by IEEE Std. C37.118.1 are performed on the same PMU with the same settings. NIST will act as the “Pivot Lab” for this ILC.

- Develop ILC charter and results spreadsheet.
- Schedule testing with each of the individual labs.
- NIST performs preliminary testing on the PMU.
- The PMU is sent to a laboratory. When the laboratory has completed testing, the PMU and results spreadsheet are returned to NIST.
- NIST will retest the PMU and send it to the next laboratory.
- Repeat until all laboratories have completed testing.

Objective: to support the ability of independent test laboratories to verify PMU model compliance with IEEE Std. C37.118.1.

Desired results: reports to individual laboratories comparing the results given by their system to those given by the test system at NIST. Publically available report comparing all laboratories to each other with laboratory identities disguised. (Laboratories will know their own identity).

4.4 Development of 61850 90-5 Input to NIST PMU Test System

Objective: advance PMU testing in areas not known to be covered by other organizations.

Desired result: better understanding of the 90-5 protocol by providing an independently designed application for PMUs to interoperate.

4.5 Third-Party PMU Test System Calibration

NIST has been a frontrunner in PMU compliance testing, yet end-product testing is not a desired role for NIST. If there is a continuing demand for PMU testing and certification, NIST prefers that work be performed by non-governmental (industry and academic) organizations. NIST may provide services to calibrate PMU test systems to ensure their compliance and traceability.

- Work with PMU end-users, NASPI, SGIP, IEEE, IEEE-ISTO, PMU vendors, and third-party test laboratories to determine whether there is demand for test laboratories that provide services to calibrate their test system.
- Act as PMU testing subject matter experts to advise in the formation of a certification body for PMU performance.
- Optional: Develop a traveling system that can be brought to third-party test laboratories to perform calibration on PMU test systems.

Objective: to support the ability of independent test labs to verify PMU model compliance with IEEE Std. C37.118.1.

Desired result: NIST will cease testing PMUs and begin calibrating third-party PMU test systems.

4.6 Time Synchronization Redundancy

Numerous governmental agencies have various responsibilities for ensuring the availability of position, navigation and time (PNT) infrastructure(s). The NIST SynchroMetrology Laboratory is studying various proposals for providing redundancy to existing PNT systems (primarily Global Positioning System, GPS) upon which electrical energy systems increasingly rely.

- Work with other NIST labs, the Departments of Energy, Defense, Transportation, and Homeland Security, plus the energy, transportation, and communications industries to understand and analyze issues and proposals for PNT redundancy as they apply to electrical energy.

Objective: identify time synchronization redundancy issues facing the electrical power industry.

Desired result: Report on time synchronization redundancy issues relevant to electric power and on the various proposals and plans to address the issues.

5. The Roadmap

5.1 IPRM Implementation

The SGTCC has a working group charged with supporting ITCAs in their implementation of the IPRM. This working group offers guidance to emerging ITCAs through publically available guideline documents, as well as through direct engagement with new programs to help answer questions and provide recommendations based on the experiences of other ITCAs. New ITCAs are encouraged to participate in this working group to develop a better understanding of the necessary activities in IPRM implementation and to take advantage of the knowledge of working group participants. The group includes participation by laboratories, accreditors and certification bodies that may also be potential partners in the development of new programs. In addition to the supporting ITCAs, this working group owns the SGTCC process for reviewing ITCA progress on IPRM implementation and administers the ITCA program list. The program list is a web-based directory of ITCAs, their testing scope, and progress on IPRM implementation. At the lowest level, an ITCA is included in the program list once they have implemented IPRM requirements sufficiently to gain basic accreditation for test laboratories participating in their program. A formal application process is in place with independent review teams established to evaluate ITCA applications. Any new ITCA for synchrophasors should set goals toward attaining placement on the SGTCC program list and avail itself of the support resources available from the SGTCC. The synchrophasor ITCA should be defined in close discussions within the stakeholder group coordinated by NASPI and in consultation with the SGTCC. The proposed IEEE ICAP effort should be coordinated with SGTCC to seek their insight and support.

5.2 Cost Considerations

As with all testing and certification programs, there are associated costs. These include the following:

- Test laboratories must purchase traceable test equipment and undergo regular calibration of their equipment.
- Test operators must be trained to understand the tests they are running and how to interpret the results.
- Complete testing of a PMU requires several to many person-days of work.
- Test reports must be written with clear indication of the test requirements.
- Test results must be sent to a certifying authority for evaluation and approval.
- The test laboratory is evaluated for compliance with ISO/IEC 17025 by an approved accreditation body and their adherence to the PMU standard.
- The certifying authority is evaluated for compliance with ISO/IEC 65 or subsequent ISO 17065:2012.
- The certifying authority must issue a certificate of conformance.
- The certifying authority works closely with the SSOs for standard improvement and clarification.

In similar programs from other industries, equipment manufacturers pay for the testing and certification of their products. These additional costs are added to the purchase price of the product. Only if purchasers of PMUs *demand* that compliant test and certification programs are utilized will those programs will be sustainable. It is expected that the testing and certification cost will be differentiated based on the importance of the PMU application (monitoring vs. control, for example).

5.3. Interests of End-Users

While the end-users are interested in the quality of products they are purchasing, and in that context would like to encourage testing and certification processes for synchrophasor products, the ultimate interest of the end-user is the performance of synchrophasor applications. Hence, while the existence of the testing and certification process is a necessary condition for making sure that the products meet standards, there may also be a need to meet the sufficient condition, which is development of performance assessment criteria that allow testing and certification of synchrophasor *applications*. Moving from the testing and certification of synchrophasor products to testing and certification of synchrophasor applications is a huge step that may eventually need to be undertaken to achieve a sufficient condition for having robust and traceable performance of synchrophasor solutions.

6. Recommendations

The Task Force on PMU Testing and Certification report highlights the need for PMU testing and certification. To achieve viability and success of a test and certification program, this requirement should be driven by end-users. End-users must understand that such a program concept is well defined by ISO standards and requires vendors to undergo certification testing by submitting their products to approved test laboratories for testing against current industry-accepted standards.

The NASPI Task Force on PMU Test and Certification recommends that

- A PMU testing and certification program should be developed and managed by an industry-recognized and -approved body.
- PMUs placed into service should be tested by an accredited test organization and the test results be certified by an accredited certifying authority for compliance with the latest PMU standard.
- Products successfully completing testing and certification should be placed in an electronic database which references the product and the certification date.
- Vendors should strive to meet the latest PMU standards by submitting products with PMU functionality to approved test organizations for test and certification.
- Should a product undergo a change or system update that could impact the performance or functionality, the PMU should be retested for compliance.
- The initial goal of PMU testing and certification should be expanded to include other components of the synchrophasor system defined by existing standards.
- The eventual goal is to develop performance assessment procedures for testing and certifying system solutions used to implement given applications.
- The cost of testing and certification should be carefully evaluated by specifying differentiated test and certification requirements for different PMU applications.

Annex A – Testing Lab Equipment and Procedures

A.1 PMU Performance Testing

IEEE Std. C37.118.1:2011 Clause 5.5.3 states that

“(a) calibration device ... shall be traceable to national standards, and have a *test uncertainty ratio* of at least (4) compared with these test requirements (for example, provide a TVE measurement within 0.25% where TVE is 1%)”.

The components that make up a “calibration device” shall be described herein. The description will be followed by a discussion of *test uncertainty ratio* (TUR) and why a TUR of 4 can lead to problems when determining whether or not a phasor measurement unit (PMU) passes any given test.

A.1.1 Calibration Device Components

In general, the following functions are required for PMU calibration devices:

1. Provide timing reference to the PMU and to the calibrator itself.
2. Provide voltage and current input signals (signal source(s)).
3. Receive measurements from the PMU under test (receiver).
4. Compare phasor, frequency and rate of change of frequency (ROCOF) measurements from the PMU to a “true” (reference) phasor, frequency and ROCOF representing the signal source input to the PMU.
5. Perform calculations for total vector error (TVE), frequency error (FE) and rate of change of frequency error (RFE), and additional calculations for the dynamic step test results.
6. Provide test result documentation.

Furthermore, tests must be made under controlled temperature and humidity conditions.

A.1.1.1 Timing Reference

PMUs under tests may require one of a variety of timing signals:

1. GPS antenna
2. IRIG B (DC level or AM possibly with the addition of IEEE Std. 1344 extension)
3. IEEE Std. 1588 (power profile)

The timing reference must be traceable to Coordinated Universal Time (UTC) and have an uncertainty $\leq 1 \mu\text{s}$.

A.1.1.2 Signal Source(s)

PMU calibration devices must provide three-phase voltage and current input signals to PMUs under test. The signals must comply with both steady-state and dynamic test conditions as specified by IEEE Std. C37.118.1:2011 Clauses 5.5.5 through 5.5.9. Additionally, the Total Harmonic Distortion (THD) of the input signal must be less than

0.2% of the fundamental (except where otherwise specified by harmonic distortion or out-of-band interference² tests).

The signals must be time aligned with UTC so that the phase A input signal is a cosine wave with time equals 0 at the UTC second. Phase offset control is also required. The phase C and B signals must be $\pm 120^\circ$ offset from the phase A signal. All tests are performed with balanced input signals.

The voltage and current amplitudes must be at “nominal level” except where specified in signal magnitude tests and measurement bandwidth³ tests. Nominal level or nominal amplitude are not defined in IEEE Std. C37.118.1:2011 and are specified by the PMU manufacturer and/or PMU settings. Typical nominal voltage level is between 65 VRMS and 120 VRMS, and nominal currents are either 1 ARMS or 5 ARMS. Signal magnitude tests require input voltage at 120% nominal and input current at 200% nominal, so PMU calibrator equipment should be capable of supplying at least 144 VRMS and 10 ARMS per phase.

A.1.1.2.1 Signal Sources for Steady-State Tests

Signal frequency range tests require input frequencies at nominal frequency ± 5 Hz. Signal sources should be capable of providing signal frequencies from 45 Hz to 65 Hz.

Signal magnitude tests require input frequencies at nominal frequencies, voltage levels from 80% nominal level to 120% nominal level, and current levels from 10% nominal level to 200% nominal level.

Phase angle tests can provide *either* constant phase at $\pm \Omega$ radians or a “slowly varying” phase angle with the input frequency ≥ 0.25 Hz from the nominal frequency for a duration that allows at least 360° of phase rotation.

Harmonic distortion tests require the addition of a single harmonic from the second harmonic up to the 50th harmonic. Harmonic magnitude must be 10% of nominal level for M-class tests and 1% of nominal for P-class tests.

Out-of-band interference tests require interfering signals at 10% of nominal level to be added to the fundamental, where the interfering signal will be from 10 Hz up to twice the nominal frequency.

A.1.1.2.2 Signal Sources for Dynamic Tests

Measurement bandwidth tests require modulation of the input signals in phase and in amplitude and phase combined. The modulation frequencies range from 0.1 Hz to 5 Hz and the index of modulation is 10%.

² Out-of-band interference tests are also called “interharmonic” tests.

³ Measurement bandwidth tests are also called “modulation” tests.

Frequency ramp tests require a linear sweep (chirp) of frequency from up to 5 Hz below to 5 Hz above the nominal frequency at a rate of 1 Hz per second. Additional downward sweep in frequencies is also required.

Step tests require steps in magnitude of nominal level $\pm 10\%$ and (separately) in phase of $\pm 10^\circ$. These tests are performed repeatedly with the relative time between a UTC second and the step being adjusted by $1/10^{\text{th}}$ of a reporting period. The PMU measurements from these 10 test “iterations” are combined to provide an “equivalent time sampled” result with a time resolution of $1/10^{\text{th}}$ of the reporting period.

A.1.1.3 PMU Measurement Receiver

PMUs may transmit their measurements over a variety of physical media using a variety of protocols:

Physical media:

1. TCP, UDP or combined UDP/TCP Ethernet via:
 - a. twisted pair copper using RG45 connector
 - b. optical Ethernet using ST or LT connectors
2. RS-232 (obsolete and may not be required for modern PMU calibration systems)

Protocols:⁴

1. IEEE Std. C37.118: 2005
2. IEEE Std. C37.118.2:2011
3. IEC Std. 61850 (using IEC TR 90-5)
 - a. Per the GE “implementation agreement”
 - b. Per a custom config file

A.1.2 Reference (“True”) Values and Result Calculation

According to IEEE Std. C37.118.1:2011, the PMU measurement is compared to the “true” value. Typically, measurement labs and metrologists do not use the word “true” because there is always some level of uncertainty in the representation of a physical quantity. The word “reference” is preferred. In order to determine the error of the PMU measurements, the phase, frequency and ROCOF of the signal source must be known at the times of the individual PMU measurements. It is also very important that the uncertainty of the reference also be known because uncertainty in the reference value contributes to the TUR of the calibrator. The TUR establishes a range of results for which it is impossible to determine whether or not the results exceed the limits of the test. There will be more on this topic later in section A.1.5.

There are several methods to determine the reference values:

1. Direct Measurement: A calibrated data acquisition system (using analog to digital converters) is connected to the signal source along with the PMU under test. Since

⁴ IEEE Std. 1344 is obsolete and will not be addressed

- the parameters of the signal are known, a combination of techniques (such as curve fitting) can be applied to determine the reference with a known uncertainty.
2. Inference: The signal source is calibrated such that, given the parameters of the signals, the reference can be inferred. Some information can be fed back into the system such as the time of the zero crossing of one of the phases.
 3. Transfer Measurement: A calibrated PMU with uncertainty that exceeds the TUR requirements for the calibration system is connected to the signal source. This “reference PMU” provided the reference signal. The drawback to this method is that PMUs do not know the parameters of the input signal and thus tend to have a higher uncertainty than either of the preceding methods.

A.1.3 Test Documentation

IEEE Std. C37.118.1 Section 5.5.3 requires that documentation of the tests shall include the following information:

- a) Performance Class
- b) Measurements that meet this class of performance
- c) Test results demonstrating performance
- d) Environmental conditions during the test
- e) Error analysis if the test system is not traceable to a national standard.

Customers for PMU calibration may require additional documentation such as descriptions of the test or certification by a certifying authority.

A.1.4 Environmental Conditions

Tests are required to be performed at a temperature of $23^{\circ}\text{C} \pm 3^{\circ}$ and at humidity $<90\%$. Some tests are also required at temperatures of 0°C and $50^{\circ}\text{C} \pm 3^{\circ}$.

A.1.5 Test Uncertainty Ratio

The TUR is the ratio between the uncertainty of a device under test and the instrument testing it. When there is a performance limit, the TUR determines a region on either side of the limit within which the test instrument is incapable of determining whether the device under test exceeds or is within the test limit. IEEE Std. C37.118.1:2008 states that a calibrator shall have a TUR of 4 *compared to the test requirements*.⁵

As an example of the effect of TUR* on TVE measurements, Figure 3 shows a phasor diagram of a single, time-stamped reference (true) value from a PMU calibrator and a single time-stamped measurement from a PMU under test. An exaggerated circle around the reference value shows a TVE limit of 1%. On either side of the TVE limit is a ring the width of the calibrator uncertainty on either side of the limit.

⁵ Metrologists normally determine TUR with respect to the uncertainty of the device under test rather than the test requirements so it is important to note that, for the purpose of this section, TUR is the uncertainty of the calibrator with respect to the test limits.

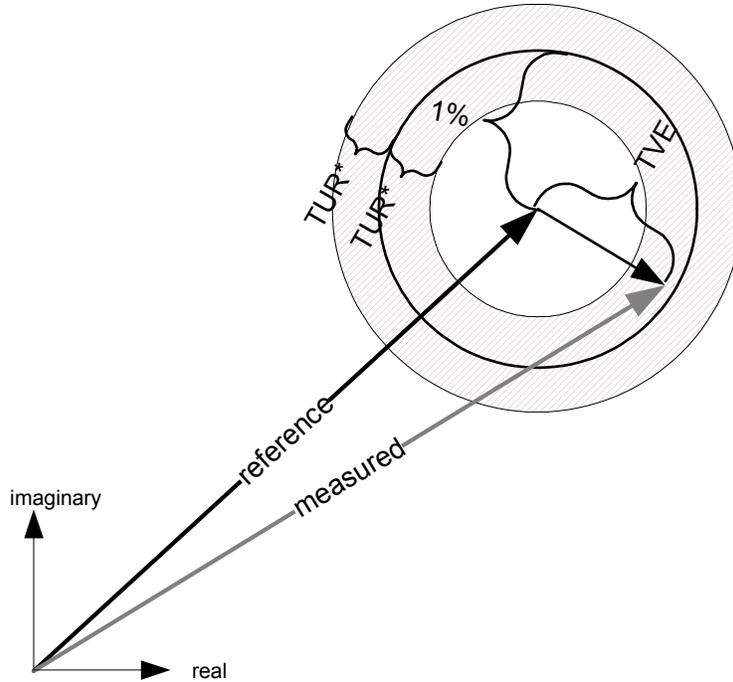


Figure 3. The Effect of Test Uncertainty Ratio*
 *TUR with respect to the test limits

Note that the measured value is within the TUR* ring around the limit. The measured value passes, but the uncertainty of the calibrator is such that it cannot be determined whether the measurement is within or outside of the limit.

For many devices, such as voltmeters, the error of the device is expected to be small, so a calibration device can have a TUR of 4 with respect to the device under test and only about 2% of tests would be indeterminate. However, PMUs are tested in such a way that their measurements are expected to be well within 75% of the limit (for example, for measurements near the bandwidth of the PMU, The TVE is expected to be greater than 0.75%). Therefore a TUR of 4 *with respect to the limit* is insufficient for a PMU calibrator. An uncertainty of .025 (TUR* of 40) would be much more appropriate and allow most test results to be determined.