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Life-cycle Testing of Synchrophasor Systems

Mladen KEZUNOVIC
Convener, CIGRE WG B5.62
Texas A&M University
U.S.A.
m-kezunovic@tamu.edu

SUMMARY

The synchrophasor systems have been recognized for some time as an inseparable part of the utility monitoring, control, and protection infrastructure. They are capable of far more precise assessment of the power system disturbances than what is available with the state-of-the-art Supervisory Control and Data Acquisition (SCADA) systems used today. The substation-located Phasor Measurement Units (PMUs) sample current and voltages at a very high sampling rate, and based on the samples, calculate voltage and current phasor values, as well as the Rate of Change of Frequency (ROCOF) at a reporting rate of 30-60 frames per second (60Hz system). Such high-resolution view significantly exceeds the measurement fidelity possible with the SCADA scanning rates of several seconds. The PMU measurements time-synchronization using Global Positioning Systems (GPS) of satellites receivers enable implementation of applications that require correlated phase angle measurement at different locations (substations). However, such systems are also highly vulnerable to variety of failures and malfunctions: possible mismatch between system components (PMUs/PDCs) from different vendors, improper design and commissioning practices, potential inherent inaccuracies stemming from non-compliance with industry standards, various hazards from malicious attacks, communication failures and/or improper calibration, and insufficient life-cycle testing practices. The testing practices can discover most of the mentioned issues.

In pursuit of such technical understanding of the testing requirements for synchrophasor systems, the SC B5 formed a WG B5.62 titled “Life Cycle Testing of Synchrophasor Based Systems used for Protection, Monitoring and Control” that was initiated in 2017 and published its findings in the CIGRE Technical Brochure TB 843 published under the same title in the late 2021. This paper elaborates on some testing recommendations and experiences reported in the brochure and adds new developments in the testing practices in recent years.

KEYWORDS: Synchrophasor-Testing-Protection-Control-Monitoring-Standards

INTRODUCTION AND MOTIVATION

Deployment of synchrophasor technology is well underway in many countries and regions around the world [1-4]. The reports from the USA, China, India, Russia, and many countries in Europe and South and Central America indicate that thousands of Phasor Measurement Units (PMUs) from different vendors combined with Phasor Data Concentrators (PDCs) are implemented in the field as synchrophasor systems used for variety of applications from state estimation [5] to fast stability control [6] and system-wide protection [7].

Synchrophasor systems may be rather complex as shown in Fig. 1.

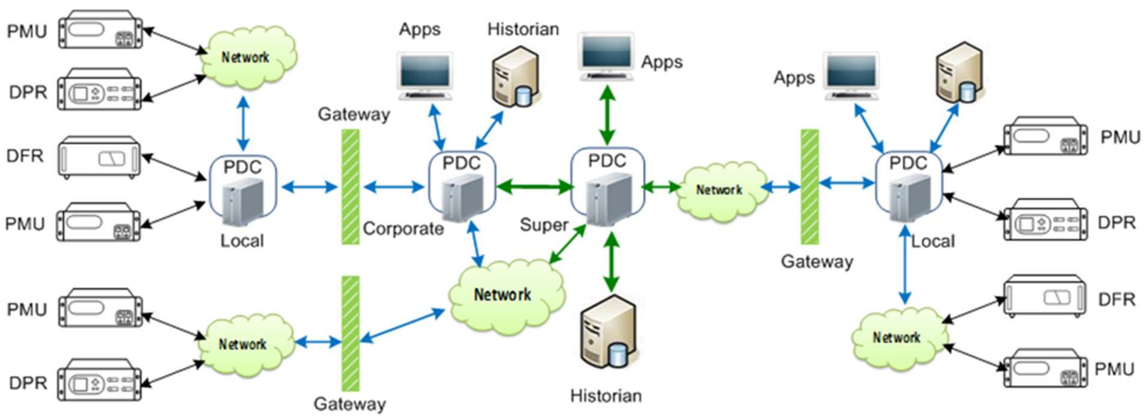

Figure 1. Synchrophasor System Implementation Options

As illustrated in Fig. 1, the field devices located in substations that collect data, typically designated as PMUs, may come in variety of designs: either as standalone devices or as algorithms embedded on Digital Protective Relays (DPRs) and Digital Fault Recorders (DFRs). Once calculated, the synchrophasors are transmitted to PDCs that may be located in substations (Local), at some utility designated gathering points such as Control Centers (Corporate), or at a location that covers the entire region (Super). The various visualization applications developed based on data available in databases, which may be updated continuously or stored to preserve historical data (Historian) for further uses.

Two critical components of the synchrophasor system are the time-synchronization [8] and communications [9]. A typical time synchronization implementation is shown in Fig. 2.

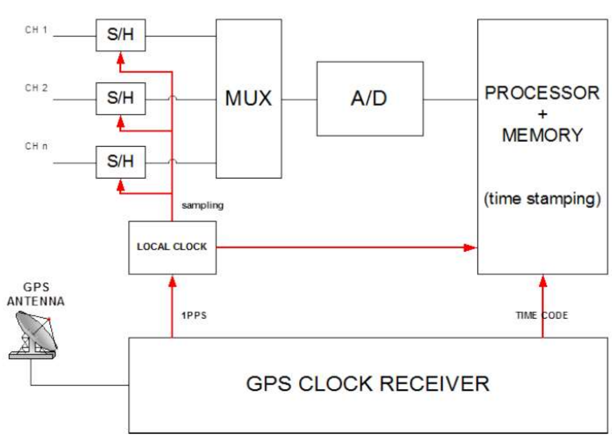

Figure 2. Typical Phasor Measurement Architecture

The time-synchronization of all PMU measurements is maintained through interfacing to the Global Positioning Satellite (GPS) System receiver, which receives and distributes an accurate time clock in a form of 1 Pulse Per Second (1PPS) signal that synchronizes all PMU's internal clocks to the same time-reference. In addition, GPS receiver provides and absolute time code that is used to time-stamp PMU measurements calculated from samples taken by Sample and Hold (S/H) circuits and converted by Analog-to-Digital (A/D) converters into a digital word. Such samples, taken at very high sampling rate in the range of nanoseconds are used to calculate phasor, which are then streamed to the PDCs at a typical reporting rate of 30-60 samples per second (60Hz) system.

Transferring phasor frames between substations and from substations to various control canters at a high-speed puts and additional burden on the communication system. As an example, communication system implemented using the IEC 61850 is shown in Fig. 3 [10].

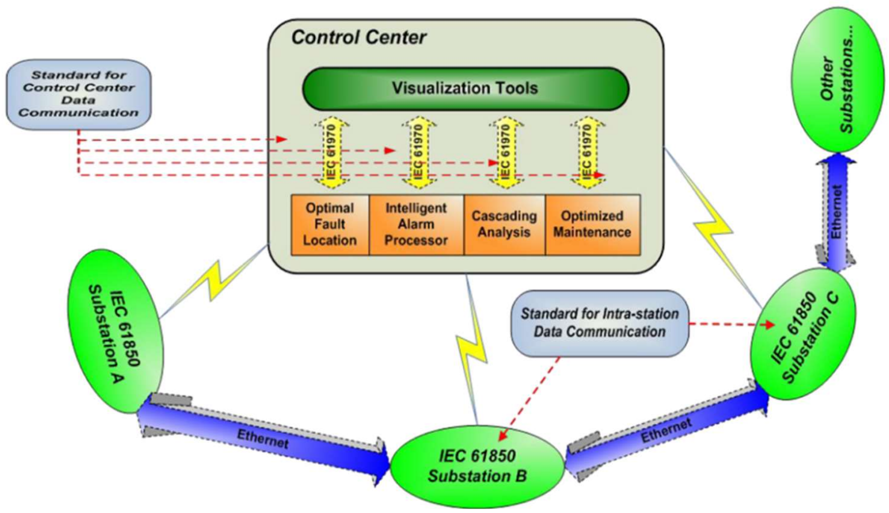

Figure 3. Synchrophasor communication system using IEC 61850

The complexity of the communication system implementation creates several design issues ranging from data compression for reducing the amount of the transferred data to cybersecurity aimed at securing data transfer and applications access. Additionally, bad data detection and correction techniques need to be deployed for data quality.

Considering the mentioned complexities and implementation challenges, it becomes obvious that selecting the components of a synchrophasor system and assembling them into a specific utility solution is a demanding task. An ultimate question is how to make sure that such solutions are designed and implemented correctly, and that their performance does not deteriorate over time as the system is updated and maintained regularly.

The vendors and utilities use best practices to assure their choices meet the expected performance requirements. The use of standards is one of the main means of assuring the systems are compliant to an agreed-upon set of requirements, and their integrity may be confirmed through the various standard compliance test procedures. While the synchrophasor standards are well developed, the common test procedures for different stages of the system design, deployment, and exploitation are not so well defined and widely accepted. This is partially due to the different uses of synchrophasor systems, and because of the different exposures to the vendor and component options in the various countries and regions.

The rest of the paper discusses the assignment of the CIGRE WG B5.62 that focused on the issue of synchrophasor system testing over the entire life cycle, from early stages of component selection, and system type and application testing, through commissioning, in-service testing and eventually troubleshooting testing in the case of component or system malfunction. The paper also discusses some new implementation and deployment requirements stemming from the IEEE Guide C37.242-2021 for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control that was published after the WG B5.62 CIGRE Brochure was published in 2021 [11].

CIGRE WG B5.62 FOCUS

The CIGRE WG B5.62 was formed in late 2017 with the Technical Terms of Reference (TOR) assignment to answer the following questions:

- What are the existing PMU and synchrophasor system standards, and what is their impact on testing and certification?
- What is the importance of the concept of interoperability, and why it matters?
- Why the certification may be needed, and who is authorized to do it?
- How certification may be accomplished, and what are associated costs?
- What are acceptance, commissioning, periodic maintenance, and troubleshooting test procedures, and how do they relate to the life-cycle management of synchrophasor systems?
- Why such life cycle test procedures matter, and how are they implemented today?
- How to plan for the PMU certification and the lifecycle testing of PMUs and synchrophasor systems?

The above questions were motivated by the life-cycle process of synchrophasor system deployment shown in Fig. 4.

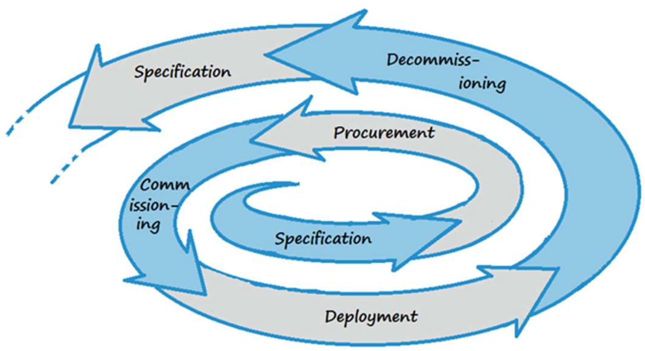

Figure 4. The life-cycle of synchrophasor system implementation

As noted in Fig. 4, the synchrophasor systems go through different stages of implementation over their life span starting with specifications, procurement of the equipment, commissioning of the system, deployment over the years, and then gradually decommissioning certain components and replacing them with newly specified ones that may have improved performance.

Addressing such issue was exploited within the confines of the available literature and practices in different countries that were shared though the WG memberships from Australia, Brazil, Canada, China, Croatia, Finland, India, the Netherlands, Norway, Russia, South Africa, UK, and USA.

During the WG Report development over the years several IEEE, IEC and local national standards were examined. Some examples of the IEEE/IEC standards that were examined to specify different test practices are as follows:

- "IEEE Standard for Synchrophasor Measurements for Power Systems - Amendment 1: Modification of Selected Performance Requirements," IEEE C37.118.1a-2014.
- "IEEE Guide for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control," IEEE C37.242-2013. (being revised during the WG tenure and subsequently published after the WG Report was already published)
- "IEEE Guide for Phasor Data Concentrator Requirements for Power System Protection, Control and Monitoring," IEEE C37.244-2013.
- " IEEE Standard for Synchrophasor Data Transfer for Power Systems," IEEE C37.118.2-2011.
- "IEEE Standard for Synchrophasor Measurements for Power Systems," IEEE C37.118.1-2011.

- “IEEE Standard Profile for Use of IEEE 1588 Precision Time Protocol in Power System Applications,” IEEE Std C37.238-2011
- “IEC Standard on Synchrophasor transfer,” IEC 61850-90-5
- “IEC/IEEE 60255-118-1 Measuring Relays and Protection Equipment – Part 118-1: Synchrophasor for Power Systems – Measurements”

An obvious target for the test practices was the overall synchrophasor system testing, not just testing of individual components. Besides, testing practices in different countries also pointed out to the different testing tools that may be used for different test implementations ranging from type and application tests to commissioning, periodic and troubleshooting tests.

SYNCHROPHASOR SYSTEM INTEGRATION REQUIREMENTS

Modern secondary systems are usually made up of equipment from multiple vendors. Sometimes this is done by necessity, for instance, when a particular vendor has a solution which offers functionality that other vendors do not. Sometimes this is because the end user prefers a particular device or solution. Often the use of equipment from multiple vendors is mandated by the end-user to minimize the effect of a common "Type fault" in the equipment of one supplier. If this occurs, there is a good chance that the equipment from the other manufacturer will not be affected. Also, there is an implicit risk in using equipment from only one vendor in case that vendor goes out of business.

Thus, there is a need to integrate equipment from different manufacturers into a complete system. The individual pieces of equipment must be able to communicate with each other using common standards – this is referred to as interoperability. This is different from interchangeability, in which any component can be swapped out with another component without affecting the functionality of the overall system. When two or more pieces of equipment are interoperable, it is possible to integrate them together, but some engineering effort will be required to ensure that they work correctly together. These concepts are particularly important for synchrophasors because these signals can be produced by a multitude of different types of devices, from stand-alone units to protection relays or dedicated fault recorders as mentioned in Fig. 1.

As a result, the WG report has recognized some important system implementation concepts that may affect test requirements as discussed next.

Interoperability and interchangeability

PMU specifications that claim compliance with standard C37.118.2-2011 should be interoperable with any PDC that is compliant with C37.118.2-2011. The big advantage is that being compliant in this case means being interoperable, and therefore an end-user could choose any PMU or a mix of PMUs from different manufacturers to work with any PDC. There is currently no designated test lab that will certify this interoperability compliance to the standard. This does not seem to be an issue as of now. It appears that all the commonly used PMUs have been sending C37.118.2-2011 data streams to any of the commonly used PDCs on the market today, and they seem to work, or if not, have been adapted to work together. Therefore, certification regarding protocol compliance for communication of synchrophasor data may generally not be required at this moment in time.

Although the current IEC/IEEE 60255-118-1-2018 synchrophasor standard provides a reference algorithm to meet the requirements set out in the standard, manufacturers are free to use any algorithms they wish to meet the outlined specifications. This basically means that all PMUs conforming to the standard should perform within the boundaries set out in the standard but can respond quite differently to applied signals and might, therefore, not always be interchangeable. For example, if one would take PMU 1 and look at its performance, it might be within the limits mentioned in the standard, but a PMU 2 from another manufacturer might perform 10x better and, of course, also be within the limits. End-users should be aware that even if a PMU does not comply with the latest standards, it might still perform well for what they want to use it for. This just points out that compliance with the standard doesn't always guarantee the best PMU for your application.

This fact does not necessarily have to cause problems, but users of synchrophasor data should be aware that this might influence an end-to-end applications performance. If someone would decide to develop an application and test it on a PMU from manufacturer 1, it does not automatically mean that this application will also run using PMUs from manufacturer 2 or in a system using a mix of PMUs from various manufacturers. Looking at applications developed today that are based on synchrophasor data, this does not seem to be a problem just yet, but as new applications evolve, this might become an issue in the future.

The more complex situation is when it comes to compliance with the data viewing and analysis software. The data formats for such software are typically confidential, so it is not easy to interchange such software packages. There is also an issue of lack of interoperability of such viewing software with some common data storage software packages such as frequently used PI Historian [12]. An important observation is that any applications which use data from multiple synchrophasors devices must consider the differences in the settings of the individual devices that produce the synchrophasor signals.

Calibration and certification

There are many PMU devices on the market claiming to be compliant with the IEEE C37.118.2-2011 standard. Some devices are standalone units, whereas others comprise of several functionalities, like protection, fault recording, metering, as well as PMU.
In large countries like the USA, China, Brazil, India, and Russia, it is very likely that different regions will deploy equipment from different vendors, or even within the same operator, they might end up with multi-vendor units in their system. Examples of PMU specification in different countries were included in the WG B65.62 Report, Appendix IV illustrating the differences. As mentioned previously, although several PMU devices from different vendors might claim to be in compliance with the C37.118.2-2011 standard, they might be within very different acceptable limits of the standard, and they use different algorithms to achieve that.
It is very important to define what is the PMU needed for, what acceptable limits the operator would be willing to approve for their specific application, and how the operator should interpret the PMU data. In this context, calibration and certification are vital to ensure the quality of the output is as expected. The difficulty is to produce a test procedure that will fit all purposes for the various units available in the market due to the differences in algorithms and output within the accuracy confines of the standard.

For this reason, it is very common for operators to produce their own set of requirements, which will consider the C37.118.2-2011 standard as well as their own local requirements. In this way, at least, some consistency can be achieved for their specific applications, without given preference to specific vendors.

The key to such considerations is the application that the synchrophasor measurements are used for. Different applications may require different certification test procedures, and this area is still largely unexplored in the industry. Future efforts may be focused on asking the vendors to offer certification test procedures for acceptance of various applications that are supported by their equipment. This becomes particularly critical when real-time control and protection applications are deployed in the future. Their performance criteria will need to be established so that they can be tested and certified. The IEEE has developed a service for certification of some of the syncrhophasor system, and such services are offered for a fee but it appears that the utilities in many countries chose to develop their own certification procedures that are typically specified and implemented in collaboration with some local well-established test labs.

Component and system end-to-end testing

This problem has different aspects: responsibility, standards, and in-house interoperability testing procedures. The responsibility aspect is focused on whose responsibility is to verify that a system that consists of many components is functioning properly. If a vendor is responsible for delivering an end-to-end solution, they should be responsible for providing test procedures to verify that such solutions are compliant with the standards. However, if the solution is created by piece-wise purchases from different vendors, then the end-user needs to decide how and by whom the overall solution will be certified, particularly as upgrades are made over time.

Since there are no standards for end-to-end implementations, any end-to-end solution testing will have to be defined in terms of component/subsystem centric standards. Any parts of the testing that goes beyond such standards will have to be defined with the help of vendors and/or consultants. As of the time of publishing of the WG B5.62 Report, no interoperability test procedures for end to-end solutions were available to review and recommend.

Backward compatibility and interoperability

The concept of backward compatibility is quite important since the synchrophasor systems are getting updated continuously. Any new equipment and software that is added to the legacy system need to be compatible so that it can operate once integrated with the older vintage. The importance of this requirement on the life cycle management needs to be addressed at the time the new additions are planned. Depending on the extent of the new additions, some parts of the system where the additions are integrated may have to be recommissioned. Typically, if the additions are purchased from the same vendor that was the original OEM supplier, it will be known what their products that are backward compatible are.

The issue is a bit more complex when the updates are purchased from a vendor that is used for the first time. In that case, the backward compatibility requirement may be addressed through a specification indicating that the new additions need to be interoperable with the legacy solutions. Whether addition of a new PMU or PDC would require acceptance testing is left to the decision of a given user. The interoperability requirements are typically imposed on the equipment and software that is purchased from different vendors than the original OEM supplier and this means that such components can be freely interchanged with the legacy solutions when integrating them into a system solution.

EXAMPLES OF LIFE-CYCLE TESTING REQUIREMENTS

This section gives a summary of testing practices in different countries. Full details are given in the CIGRE WG B5.62 Report, APPENDIX F.

Existing testing steps

In *China*, it was reported that PMU testing is divided into three steps:

1) Commissioning: Before deploying PMUs into power systems, two steps are taken to ensure the measurement performance. Firstly, each vendor selects a PMU prototype to be tested in China Electric Power Research Institute. Secondly, vendors test their PMUs by themselves in their laboratories.
2) Periodic tests: When PMUs run in a power system for some time, the measurement accuracy will decrease due to hardware aging and other reasons. Thus, periodic tests

organized by the State Grid Corporation of China for PMUs are carried out to ensure continued high measurement performance of PMUs.
3) Troubleshooting tests: In a regional power grid, if the measurement results of one PMU are different from other PMUs or measurement devices, the PMU must be tested to find out the causes.

The PMU testing practices reported from *Finland* can be divided into tests that are performed when the devices are commissioned (commissioning tests) and tests that are performed periodically after the commissioning (periodic tests). In this classification, testing related to research and development activities is not considered.

In *Russia*, SO UPS had organized the System of Voluntary Certification (SVC). The requirements for the certification organization are defined in the national standards. These documents regulate the procedure for voluntary certification and procedures for admission of SVC to the certification process. Since 2017, all PMU & PDC vendors in Russia must be tested and certify their devices by an independent organization.

In *Brazil*, steady state tests, dynamic tests, and latency test tests have been performed in the Energy Research Center-CEPEL, verifying if the PMUs comply with the standard IEEE C37.118.1.

Existing testing tools

As reported, two kinds of PMU testing platforms have been built in *China*. One is based on a high-precision commercial signal generator, a standard offering of field test instruments. In this testing system, the signal generator is treated as a reference source. Another PMU testing system is based on a PMU calibrator, where the PMU calibrator provides reference values.

In *Finland*, there are no specific requirements regarding testing tools. However, real-time digital simulator systems and commercial precision signal generators are being used for PMU testing.

In *Russia*, testing platforms for PMU and PDC testing are built using commercial real-time simulator. PMU and PDC certification is carried out in accordance with the national standards:

- “PMU Requirements” based on IEEE C37.118.1 and IEEE C37.118.1a-2014 addendum.
- “PDC Requirements” based on IEEE C37.244.

In *Brazil*, a commercial PMU calibrator is used for lab testing. As a result, the vendor adjustments in hardware or software before field installation are suggested.

Existing testing practices

As reported, the *Chinese* EPRI is using two testing systems to test all the PMUs from the Chinese PMU manufacturers before their installation. As an example, PMUs from four manufacturers were tested in 2010 to evaluate their measurement performance. Test results showed that the measurement accuracy of PMUs is high under steady-state conditions, but the measurement errors do not meet the requirements in Chinese standards under dynamic conditions. Then, in 2013, the tests organized by China Electric Power Research Institute were performed to evaluate the performance of improved PMUs from seven manufactures in China, where most PMUs’ performance satisfied the requirements. In addition, a troubleshooting testing was undertaken as described next.

In May 2018, one vendor's PMU measured the following results: three-phase amplitudes were modulated at a frequency of about 0.14Hz, but positive sequence amplitude was non-modulated; frequency was also modulated at the same modulation frequency. The measured amplitude and frequency from other PMUs and measurement devices were not modulated, but the fundamental frequency was offset to about 49.93Hz (nominal frequency is 50Hz). After a series of tests, it was determined that the PMU cannot measure the phasor and frequency accurately under the condition of the fundamental frequency deviating from nominal frequency, resulting in amplitude and frequency oscillations. Positive sequence amplitude was not modulated because the oscillations in three phases were cancelled out.

In *Finland*, the existing PMU testing practices experiences are as follows: There are no specific commissioning test requirements for PMUs that are being used only for power system monitoring. PMU devices used for control, for example in SVC installations are commissioned together with the SVC control systems.

Also, there are no general periodic test requirements for PMUs that are used for power system monitoring. The same applies to PMU devices that provide control signals for SVCs or other controlled FACTS installations. It is currently being investigated if PMU devices providing control signals for SVC or FACTS installations would require periodic testing. The key target in the testing of the PMU devices controlling FACTS devices would be to verify the accuracy and latency of the measurement unit that is essentially part of a control system that is critical for the power system stability.

In *Russia*, it was reported that the existing PMU and PDC testing practices follow certification carried out in accordance with the requirements of national standards.

Each WAMS of Power Station and Substation including PMUs and PDC had been tested during one week before being put into operation for the following requirements:

- Correct time synchronization.
- Correct synchrophasor of angle measuring.
- Archive creation function.
- Clarification of compliance of transmitted PMU data in regional PDC.

SO UPS supports the strategy of constantly monitoring PMU and PDC operation and they reportedly developed software for automatically monitoring PMU data. As experience shows, daily end-to-end monitoring of PMU data quality in a large distributed system is very effective. The National Standard requires owners to perform periodic maintenance to target WAMS complexes.

In *Brazil*, several experiences were reported from testing PMUs in the lab environment by CEPEL. A specific model of PMU was tested for the first time, and some non-conformities were detected regarding frequency and ROCOF measurements in the static tests. The vendor did some modifications in hardware and software, and the PMU was verified again. The problems identified at the first tests were solved, but new non-conformities appeared at the step tests. The manufacturer was informed and modified the firmware again. Finally, the PMU was compliant with the standard. During the last few years, the lab has been testing PMUs from more than six different vendors, some of them present in the Brazilian Electric System. Further details are given in the WG B5.62 Report.

NEXT STEPS

The testing of synhrophasor systems discussed in the previous sections illustrates that the testing practices in the various countries are based on very specific needs and experiences emerging from the uses of synchrophasor technology. The newly published version of the

IEEE Guide C37.242-2021 defines much more elaborate test procedures than what is reported in practice, but also indicates that the test requirements and practices depend very much on the applications of interest. The CIGRE WG B5.62 offered several next steps suggestions:

- End users should persist in looking at the synchrophasor systems in a holistic way by defining the life-cycle test and calibration procedures. If such proceedings are not in place in some utilities, they should be developed.
- Vendors should be ready to offer and perform interoperability tests as needed to verify that end-to-end legacy systems may be upgraded with a variety of products on the market going forward.
- Standards organizations should develop procedures for application testing that will also encompass end-to-end testing of the underlying synchrophasor infrastructure.
- Consultants, vendors, and academic researchers should look into the fundamentals needed to better understand the synchrophasor system performance under transient conditions and recommend adequate calibration and test procedures beyond what is currently defined in the standards.

Based on the recent applications and test experiences after the WG Report was published, several additional activities for the next steps may be recognized as discussed next. They go beyond what the CIGRE WG B5.62 Report and IEEE Guide C37.242-2021 are discussing.

Nested end-to-end system testing methodology

This type of testing methodology emerged as being very effective when testing components of the synchrophasor system, as well as their system integration and eventual use in applications [13]. As reported, the test methodology may be presented as the nested steps described in Fig. 5.

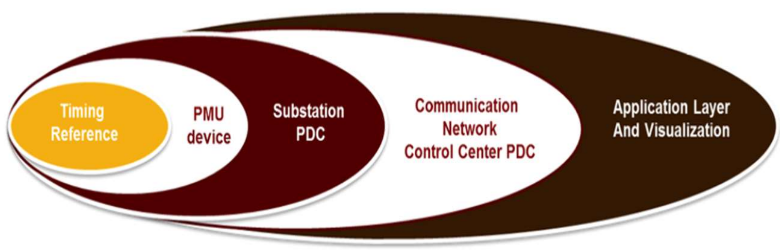

Figure 5. Nested testing of synchrophasor systems

As Illustrated in Fig. 5, the suggested test methodology starts with testing the GPS time reference and continues with testing the PMUs, substation PDCS, communication networks and Control Center PDC, and ends with the application testing. The nested portion assumes that each time an additional component of the synchrophasor system is added, the entire system up to that point is tested including re-testing of the parts that were tested before by this time they are tested with an addition of a new portion of the system. This methodology assures troubleshooting since if there is an issue with the results of the nested loop, and the previous “loop” tested correctly, the indication is that the added part has been the reason.

Implications of emergence of machine learning and digital twins

In the last few years an increase in automated means for analysing PMU data was noticed through number of studies undertaken in the USA by Department of Energy, and across many other regions and countries. This need was created by the fact that large amounts of PMU data is collected in the utility Control Center reaching the point where operators are overwhelmed and cannot analyse the data and make decisions effectively and timely.

Since the synchrophasor systems are becoming an indispensable addition to the Energy Management System infrastructure for monitoring, controlling, and protecting the overall utility power grid, cybersecurity issues have also reached a point where more assurances are needed that the synchrophasor solutions are protected against malicious attacks.

In response to the new needs, two new developments in the synchrophasor tools for automated analysis have been recently reported in the literature, namely the machine learning (ML) for automated analysis of PMU recordings [14] and digital twin (DT) for extensive analysis of synchrophasor systems during cybersecurity attacks [15].

With such new developments, future research, and technology development and deployment needs to focus on new testing tools and methodologies to support testing of ML applications and utilizing the digital twins for testing cybersecurity solutions.

RECOMMENDATIONS

As a result of the WG activities, several recommendations were offered:

Future testing protocols. While several standards have been developed over the years that may be instrumental in defining the life-cycle test procedures, the newly published IEEE Guide C37.242-2021 "Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control," is the most comprehensive test requirements document currently available and should be reviewed by all the owners of synchrophasor systems to establish the best practices.

Future testing Tools and Methodologies. As the PMU gets applied to more critical real-time applications such as control and protection, more rigorous testing practices should be developed, particularly in-service testing. The end-to-end testing that includes applications is not well defined either. Combined effort of the research community, vendors and suppliers of consulting services should be focused on addressing such urgent end-user needs.

Staff Training. It has been recognized that end-users do not have enough highly qualified staff that may be trained how to calibrate, test, maintain and monitor the performance of the synchrophasor systems. It is recommended that such practice be changed by recognizing the importance of testing and allocating adequate resources to perform related tasks. Recently initiated CIGRE WG B5.82 focused on education and training of utility staff is an opportunity to further explore the needs in this area.

Distribution applications of PMUs. It will be highly desirable that future Study Committee B5 efforts in the synchrophasor life-cycle management area are focused on the distribution PMUs (DPMUs). This area is rapidly expanding and yet has different requirements than the transmission applications. In many countries around the world, DPMUs projects are underway, and the industry needs guidance regarding lifecycle management, so forming a WG to address such issues will be timely.

CONCLUSIONS

Overall, synchrophasor systems will need more scrutiny in the use of calibration and testing of end-to- end solutions. To ensure adequate performance, the specification requirements for life-cycle management of synchrophasor systems will need to be developed. In most end-user organizations, further upgrade of the existing practice, and additional training of the related staff will be needed.

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