Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-27 (2016) 073–078

Life Cycle Management Tools for Synchrophasor Systems: Why We Need Them and What They Should Entail

M. Kezunovic, A. Esmaeilian, T. Becejac, P. Dehghanian, C. Qian

Department of Electrical & computer Engineering,
Texas A&M University, College Station, TX 77843, USA.
(E-mail: kezunov@ece.tamu.edu)

Abstract: A synchrophasor system solution generally incorporates precise timing sources, Phasor Measurement Units (PMUs), Phasor Data Concentrators (PDCs), communication network and phasor based applications. Even though all components may pass the laboratory tests, there is no guaranty that everything will work properly together after installation and deployment in the field. To preserve an acceptable level of service quality, the system components need to be tested keeping in mind different stages of the deployment. This paper discusses various aspects of a comprehensive life-cycle management model for Synchrophasor technology, ranging from the component to the overall end-to-end system level, and rigorous procedures for testing and evaluating such mission critical systems. In this effort, a unique PMU calibration lab is constructed to execute standardized PMU acceptance tests according to IEEE and IEC standards, such as the IEEE C37.118.1a among others. Field end-to-end calibrator is introduced using an accurate reference PMU called "Gold PMU" to perform field acceptance and periodic maintenance tests utilizing the nested testing concept. To illustrate the value of synchrophasor life-cycle management tools, use cases for state estimation and fault location application end-to-end tests are implemented to evaluate impact of accuracy deterioration and component failure on the performance of the synchrophasor system.

Keywords: Calibration tests, field end-to-end testing, life-cycle management, phasor data concentrator, phasor measurement unit, synchrophasor system.

1. INTRODUCTION

Deployment of Phasor Measurement Units (PMUs) and PMU-based Intelligent Electronic Devices (IEDs) over last 30 years has facilitated an understanding of modern power systems through high-resolution and precision observation. PMUs now serve as the backbone of various critical applications in electric industry such as State Estimation, Fault Detection, Remedial Actions, and Wide Area Monitoring [Singh (2011)]. Over time, issues such as the use of different synchrophasor estimation methods in various PMU products offering inconsistent accuracy, as well as difficulties in integration of proprietary software and hardware features of different products from different vendors are hindering the wide implementation of synchrophasor technology [Martin (2007)]. To ensure the system robust operation and reliable performance, testing tools must be developed to certify PMUs and perform field end-to-end tests during the system life cycle management evaluation stages: acceptance, commissioning, maintenance, troubleshooting, interoperability compliance, etc.

Multiple efforts have resulted in standards and guides for PMU testing and calibration. Since 2005, standardized testing and evaluation for PMU static and dynamic performance have been proposed. IEEE C37.118.1-2011 standard defines performance requirements for synchrophasor measurement. In 2014, this standard was revised, where some tests were removed and some of the requirements were relaxed because none of the PMUs available at that time in the market could comply with the standard. Testing procedures and requirements for the test equipment, such as timing reference, signal source, calibration device, and environmental conditions, are given in IEEE Synchrophasor Measurement Test Suite Specification (TSS) document published by IEEE Conformity Assessment Program (ICAP). TSS provides a suite of unambiguous test procedures in accordance with the Smart Grid Interoperability Panel (SGIP) Recommendations contained in the Interoperability Process Reference Manual [Gunther (2014)]. IEEE C37.118.2-2011 standard covers the requirements for the PMU data transfer in power systems. IEEE C37.242 document provides guidance for synchronization, calibration, testing, and installation of PMUs applied in power system protection and control. Testing procedures for the Phasor Data Concentrators (PDCs) are given in the IEEE C37.244 Guide for Phasor Data Concentrators Requirements for Power System Protection, Control, and Monitoring. Several organizations have been developing PMU test systems in accordance with these standards. Synchro-Metrology lab was built at NIST in 2006 [Stenbakken (2006)], and has developed static and dynamic test systems in [Stenbakken (2007a)] and [Stenbakken (2007b, 2008)], respectively. Recently, Fluke Company has promoted a commercial PMU calibration system, which complies with IEEE C37.118.1-2011 [Fluke (2011)].

Most recently, the idea of "Gold PMU", which is a highly accurate PMU empowered by carefully devised

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.10.722

synchrophasor algorithms, is proposed to be incorporated in PMU testing procedure [Qian (2016)]. The concept of end-to-end testing has been established in literature [Meinhardt (2008); Apostolov (2012, 2014); Turner (2013)]. An example of such end-to-end testing of protection system and fault clearing system is discussed in [Apostolov (2012); Turner (2013)] where the overall engineering process of system study, protection concept, design, purchase, build, and installation is described.

This paper is organized as follows. Section 2 covers the concept of life cycle management. Section 3 describes the use of newly developed testing tools through description of various tests: calibration of PMUs in the lab, and end-to-end evaluation of the synchrophasor system in the field. The same section describes the use of the reference PMU called "Gold PMU" to perform field acceptance and periodic maintenance and troubleshooting tests utilizing the nested testing concept. To build more insight into the life-cycle management tools, two application use cases to preform end-to-end testing of the synchrophasor system are also described in this section. Section 4 presents the conclusions, and References follow.

2. LIFE CYCLE MANAGEMENT

The synchrophasor infrastructure is a mission critical system introduced to improve monitoring, control and protection performance of the power grid and is expected to operate reliably each time it is called upon. A possibility that the system components have some random failures or do not meet certain performance prescribed by standards is, hence, a realistic scenario, particularly when the system is being initially commissioned or deployed in service for a long time (see Fig. 1). The "bathtub curve" in Fig. 1 illustrates typical equipment failure behavior over its life-cycle. The curve actually maps the rate of infant mortality failures of equipment at the early commissioning stages, the rate of random failures during the equipment useful life-span, and eventually the rate of wear and tear failures when the equipment designed lifetime is exceeded [Klutke (2003)]. Having a rigorous procedure and adequate tools to test different aspects of the hardware and software design, from the component to the overall system level, and over different time spans is the only way to assure a robust and reliable operation of the mission-critical systems. Systematic life-cycle management practices are needed to achieve that goal. While there are several life-cycle models for the equipment and complex systems, the strategic question is which model best fits the project. Waterfall model, iterative/incremental model, closed-loop model and spiral model are among the well-known life-cycle management models [Basu (2015); Hundal (2001); Myers (1999)]. The suggested life-cycle model for the synchrophasor systems is a risk-reduction oriented "spiral" model as demonstrated in Fig. 2.

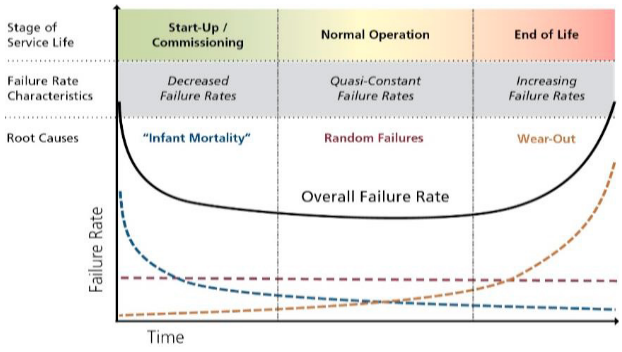

Fig. 1. Bathtub curve of a product/equipment over its life-cycle

The spiral model depicted in Fig. 2, is a comprehensive life cycle model which addresses very nature of the synchrophasor systems, which consist of multiple components provided by different vendors. Because of such nature, the expectation is that various components will deteriorate or be upgraded at different times requiring the life cycle process to unfold in a "spiral" fashion indefinitely repeating the cycles with each new change. In a spiral life-cycle model, each cycle is initiated with the specification of the following [Myers (1999)]:

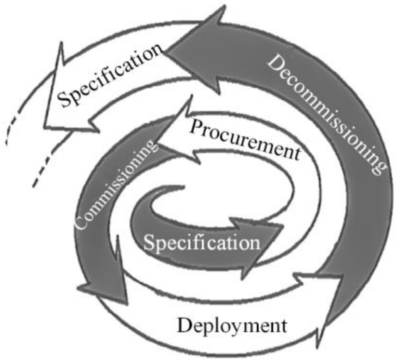

Fig. 2. The spiral life-cycle management model

- The main objectives of the (portion of the) system such as its performance, functionality, ability to accommodate any specific desirable change, etc.;
- The alternatives for implementation of the (portion of the) system such as design A, design B, reuse, buy etc.;
- The other constraints related to alternatives' application such as imposed cost, schedule and interfaces.

The unfolding spiral life-cycle model ensures the acceptable performance of the overall system by continuously testing the facilities and amending the shortages and/or new requirements. With the proposed tools within the suggested spiral life-cycle management model adapted to the synchrophasor landscape, the users of such mission-critical systems will be able to perform life-cycle long testing and maintenance procedures, which are essential for sustained wide use of such systems in real world. In the example of the synchrophasor systems, the life cycle procedures will cover:

- Equipment (PMU, PDC, etc.) calibration and certification before purchase
- System commissioning, and commissioning of any upgrades using standard test procedures
- Periodic field maintenance testing and calibration as well as testing and troubleshooting on demand
- Continuous checking of software for bugs and hidden failures using periodic tests
- Operator awareness of any system quality of service deteriorations detected by the proposed tools