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Balancing Technology and System Reliability – Methodology for Deploying Advanced Technology

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Abstract

New system solutions need to be introduced and deployed carefully to ensure good value to the user, effective deployment of technology, and reduced risk of stranded assets. This paper presents a methodology consisting of three effective steps for successful deployment of production-grade systems designed to perform and support disaster recovery environment. The article focuses on the deployment of most advanced technologies associated with the synchrophasor solution in electric power utilities. The steps include establishing requirements and specifications, implementing a real-time proof-of-concept (POC) performance validation center, and full deployment including end-to-end testing. Establishing such a facility is essential for successful deployment of production-grade advanced technologies in the field and at the enterprise level, and is indispensable in paving the path for effective and accelerated rollout of business cases.

Introduction

Accurate time synchronized measurements (e.g., synchrophasors) across the electric power system have long been needed to enable and improve various power system applications. The advent of technology has made innovations and the vision for production grade systems come true. Proliferation of energy mixes at transmission and distribution, rapid technological developments, reliability and regulatory challenges, and managing existing infrastructure while responding to the future are key challenges our industry has been facing. Successful journey along the path of infrastructure deployment and grid reliability has become more achievable with the synchronized measurement technology.

Synchronized measurement technology can support many functions, including situational awareness, wide-area monitoring, advance warning systems, protection, and control applications. The technology can also be used for daily system operation and asset performance monitoring. The present state estimation (SE) functions, supported by Supervisory Control and Data Acquisition (SCADA) systems, provide some basic monitoring. Inaccuracies in measurements and system models, absence of redundancy in the measured parameters or breaker statuses in most cases, as well as lack of synchronization and time resolution in the SCADA data result in limited functionality and precision for the typical Energy Management System (EMS) required in today's operating environment of tighter margins that require more frequent and precise data. The addition of synchrophasor data, typically having two orders of magnitude higher resolution, (i.e., 60 or 120 measurements per second as opposed to one measurement every 4 to 8 seconds), can help detect higher speed phenomena and oscillations in the power system. Also, time synchronization to one micro-second allows for accurate comparison of phase angles across the grid and identification of major disturbances, such as voltage instability and islanding. The synchrophasor technology is identified as the key technology to help detect and prevent wide-spread blackouts across the power system.

The new generation of synchrophasor applications has moved beyond prototype to the Proof of Concept (PoC) stage. Once validated and accepted by end users, and after field installation and training, these tools will become part of the next generation production EMS. The synchrophasor applications such as Linear State Estimator (LSE), Oscillation Detection, Voltage Stability indicators, etc. are in deployment stages and clear criteria for parameter set-points for triggering events are required for each application. Enhanced tools to validate results and advanced simulation tools for training are other areas for development.

To deploy a practical synchrophasor system, several factors have to be considered. A synchrophasor system consists of a number of elements, including measurement devices known as Phasor Measurement Units (PMUs), data processing and alignment devices referred to as Phasor Data Concentrators (PDCs), various telecommunication devices including routers and switches, telecommunication infrastructure usually spanning over several hundreds of miles, and intelligent functions and software applications running on various computers and processors throughout the synchrophasor system.

A production grade synchrophasor system design and architecture need to satisfy a number of key requirements including cyber security, low-latency, large data throughput (bandwidth), high availability and reliability, and maintainability. Also, consistency amongst all measurements (including measurements during dynamic conditions) and interoperability among devices used are critical for the functions deployed in a wide area system. Accordingly, ensuring accuracy of measurement devices and conformance to requirements is paramount for a well-functioning and sustainable system.

Methodology

PG&E, with the support of a DOE Smart Grid Investment Grant, is implementing a production grade synchrophasor system with resiliency for a disaster recovery infrastructure, with a number of advanced applications, both at the control centers and at the substation level. The objective is to engineer a secure, reliable and sustainable synchrophasor system that supports improved grid operation and business decisions. The following functions are amongst key functions supported by the PG&E's synchrophasor system:

- Situational Awareness, Visualization and Alarming for Electric Transmission Operators,
- Enhanced Energy Management Systems and State Estimation for current EMS users,
- Linear and Distributed State Estimation
- Post-Disturbance Event Analysis for Planners and Engineers,
- Voltage Stability Management,
- Operator and Engineering Training, Enhanced Dispatch Training Simulator (DTS),
- Providing interfaces with EMS and with third parties, and
- Cognitive task and performance analysis.

To support the process of achieving a reliable and maintainable system, PG&E has established an innovative 3-step process:

1. development of system requirements and specifications,
2. engineering and implementing a real-time proof-of-concept (POC) performance validation center, and
3. full deployment and end-to-end testing.

Proof of Concept Facility

Developing a large scale proof of concept (POC) facility has been a critical step in establishing a successful production grade system while minimizing the huge cost of stranded assets in this era of rapidly-moving technology and the need for ever-increasing interoperability standards. The PG&E POC has facilitated the development of several key product features and industry standards. PG&E's POC facility is used for testing, validating, and improving various PMUs, PDCs, GPS clocks, networking devices, and advanced application.

Some of the key benefits of using POC that have been realized during the deployment of the large PG&E PMU system are summarized below:

- Risk management: Identified and remedied product and system integration issues prior to installation on the grid.
- Identification of standards' gaps: It has served as a conduit to the industry standards.
- Provided solutions to integration issues with potential for serious delays during field installation.
- Fine tuning applications for functionality and performance.
- Transition from development to operation for training future users.

PG&E plan is to continue using the POC facility after the project is completed to support continuous improvements, software and hardware upgrades, and other operation and maintenance functions.

POC Hardware and Dataflow

Figure 1 shows a simplified architecture of the synchrophasor system at the POC facility. This facility is a fully functional smaller scale synchrophasor system, including 20 PMUs, 2 substation grade PDCs, 2 control center PDCs (Super PDCs), redundant EMS systems, 6 GPS clocks with IRIG-B and IEEE 1588v2 timing information, a PMU emulator capable of emulating over 50 PMUs, a Real Time Digital Simulation (RTDS) system capable of modeling PG&E's entire 500 kV system and providing over 40 virtual PMUs, a number of network switches and routers, a network impairment device to

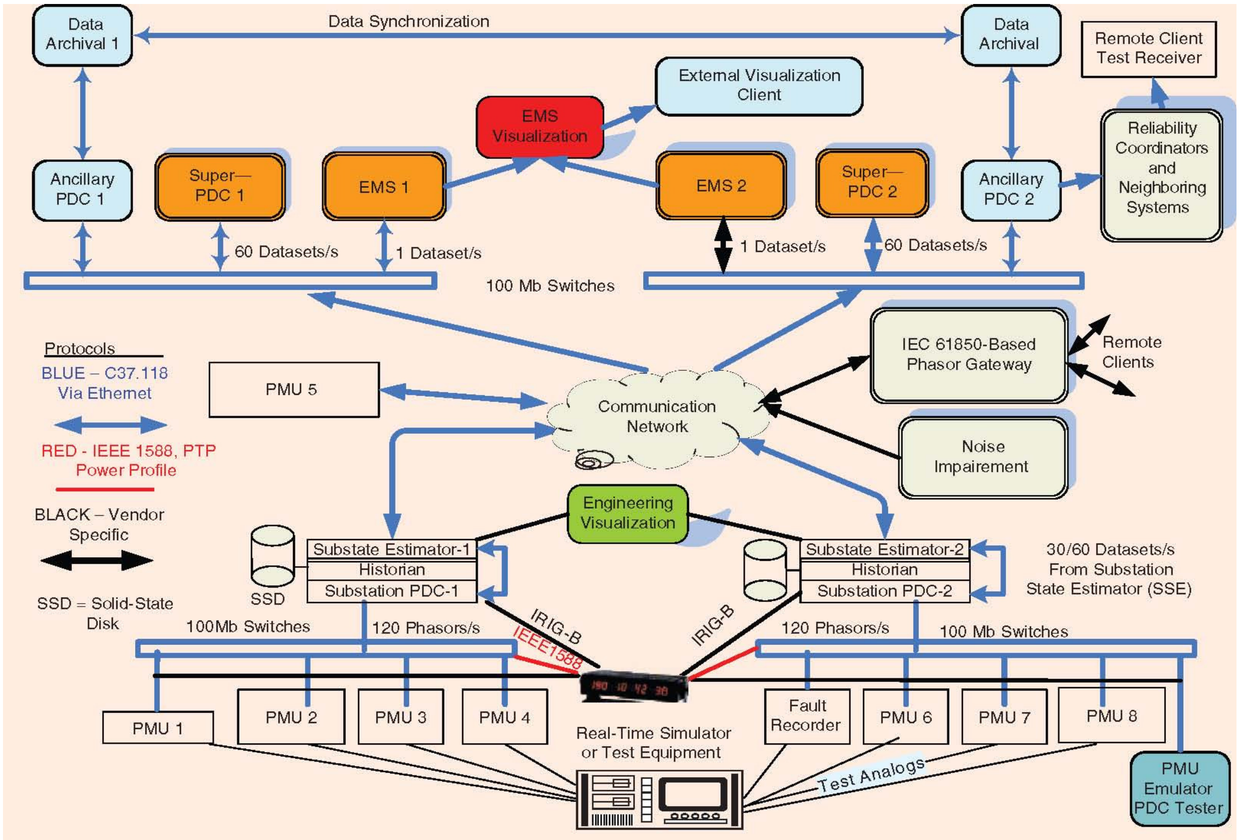

Fig. 1. Simplified architecture of the synchrophasor system at the POC facility.

emulate network communication issues, and a number of multi-purpose test equipment and amplifiers. Figure 2 shows a picture of the hardware used at the POC facility.

Fig. 2. PG&E's synchrophasor system Proof-of-Concept (POC) facility, Northern California.

The POC system also includes a number of advanced applications such as Enhanced Fault Locations, Automated Event and Disturbance Analysis, a Substation State Estimator (SSE), a distributed Linear State Estimator (LSE), a synchrophasor-based Real-time Voltage Instability Indicator (RVII) application, as well as a wealth of visualization and situational awareness applications running on a number of computer servers and workstations.

This pioneering facility has served to test interoperability between various devices (e.g., PMUs and PDCs from various manufacturers). As a result, the POC was instrumental in verifying how different manufacturers interpret relevant standards and in developing implementation agreements (e.g., implementation agreement for IEC 61850-90-5). Some tests at this facility have been used for providing specific feedback into developing standards and guides, e.g., IEEE PC37.242 Guide for PMU Testing and Installation, and IEEE PC37.244 PDC Guide. As the PG&E synchrophasor project has been funded in part through the DOE Smart Grid Investment Grant program, it is important to note that it supported major interoperability initiatives by IEEE PES, NIST, NASPI (North American Synchrophasor Initiative) and CIGRE that helped with fast track development of industry guides and standards.

The POC facility is used to perform network traffic monitoring, cyber security testing, as well as specific conformance testing for PMUs and PDCs, establishing how these devices meet project and standards requirements.

Application Validation and Training

The POC activities include validation of analytics as well as advancing the technology. Product suppliers have made several enhancements to their products as a result of the findings at the facility. Situational awareness and visualization products are verified and enhanced at this facility, while system operators, dispatchers, and operation engineers provide feedback to customization of these visualization tools. Various system level functions, applications, and control center analytics are simulated and tested at the POC facility, including oscillation monitoring, event detection, enhanced fault location, state estimator model validation, enhanced state estimation, and real-time voltage instability indication (RVII), e.g., see [1] and [2].

Using an RTDS model of PG&E's 500 kV system at the POC has been invaluable for validating system functions and applications in near-real-life conditions. For example, the enhanced fault location application is tested, and improved, using a range of faults simulated using the RTDS system. Also, the RVII application is validated for monitoring active and reactive power margins for voltage stability indication using the RTDS system through switching lines and components within and/or outside of the transmission corridor being monitored by the PMUs. Figure 3 shows an example of measured active and reactive power margins for power flow through a corridor provided by the RVII function through the switching of a number of 500 kV lines in the RTDS system.

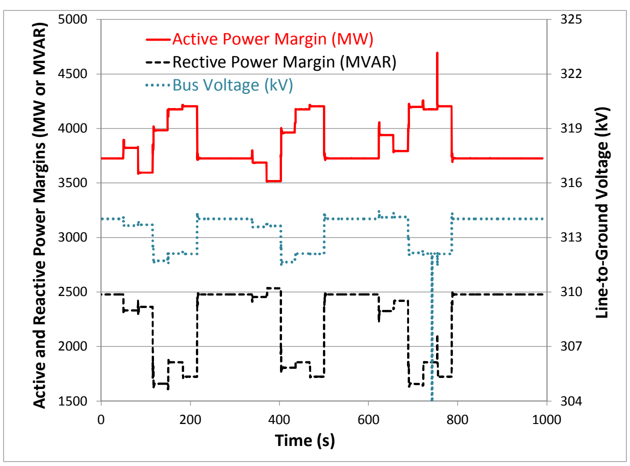

Fig. 3. Active and reactive power margins measurement using the Real-time Voltage Instability Indicator (RVII) application at PG&E's POC facility while various 500 kV line switchings being simulated using the RTDS. One of the corridor bus voltages is also shown.

The POC facility has made it possible to accelerate the transition from data to actionable intelligence; where tools for data mining have been fully vetted and visualization tools developed.

The POC facility is also used as a training ground and simulation facility for various stakeholders at PG&E, including field technicians, different engineering disciplines such as EMS, operation and planning engineering staff, and system dispatchers. Field installation and commissioning procedures are developed using the experience at this facility.

Summary and Conclusions

New technologies in general, and Smart Grid solutions in particular, should be tested as a system, and refined prior to wide-spread deployment to ensure good value to the consumers and positive return on investment. This is a necessity for the effective deployment of technology, establishment of key management tools, and minimizing stranded assets. PG&E's synchrophasor system proof of concept test facility is an exemplary facility focused on synchrophasor system and device testing and refinement, as well as training and familiarization of various stakeholders. Establishing this facility has been indispensable in paving the path for effective and accelerated deployment of synchrophasor systems at PG&E and the associated power systems applications. It has also served the entire industry by supporting standard development and sharing lessons learnt among researchers and developers of this important technology.

The PG&E project is now in its final stages of field deployment using the templates and standard set points developed at the POC facility, and incorporating the lessons learned with support of the various solution providers.

Acknowledgement

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References

[1] J. Giri, M. Parashar, J. Trehern, and V. Madani, "The Situation Room: Control Center Analytics for Enhanced Situational Awareness," *IEEE Power & Energy Magazine*, September / October 2012.

[2] M. Glavic, D. Novosel, E. Heredia, D. Kosterev, A. Salazar, F. Habibi-Ashrafi, M. Donnelly, "See It Fast to Keep Calm: Real-

Time Voltage Control Under Stressed Conditions," *IEEE Power & Energy Magazine*, July 2012.

[3] A. Jampala, V. Madani, M. Glavic, R. King, J.Giri, "Practical Challenges of Integrating Synchrophasor Applications into an EMS", *IEEE ISGT (Innovative Smart Grid Technology),* Washington, DC, February 27, 2013.

[4] IEEE Std. C37.242 - *IEEE Guide for Synchronization, Calibration, Testing, and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control*, May 2013

[5] V. Madani, R. L. King, "Roadmaps for Deployment of Advanced Warning Systems to Improve Overall Grid Reliability: Setting the Stage*", Proc. of IEEE PES General Meeting*, Minneapolis, MN, July 2010.

[6] V. Madani, M. Adamiak, H. Falk, D. Baigent, "An Overview of the new IEC 61850 Synchrophasor Publish-Subscribe Profile", Distributech, San Diego, CA, January 2013