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Transforming Synchrophasor Measurements into Situational Intelligence

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SUMMARY

The utility industry at large has made significant investments in deployment of production grade Wide Area Monitoring Systems (WAMS) and synchrophasor technology in recent years with now well over 4,000 Phasor Measurement Units (PMUs) globally. In North America, the US Smart Grid Investment Grants (SGIG) have resulted in a massive influx of installed Phasor Measurement Unit (PMU) expanding from approximately 200 research-grade units to over 1,700 production-grade devices in less than five years. The growth is further expanding to large scale generation units as well as distribution systems. The business case for PMU installations could not have been possible without the applications to gather, analyze and visualize the high resolution time-synchronized data and associated information. Thanks to the global industry recognition of the Synchrophasor technology, production grade solutions have also been manufactured, tested, and installed in utility and ISO control rooms worldwide.

This paper outlines ongoing efforts at Pacific Gas & Electric (PG&E) towards adoption of synchrophasor technology including a state-of-art Proof of Concept (POC) facility that has been engineered for validating and maturing innovative applications such as PMU-based voltage stability management and linear state estimation before the applications can be rolled out into the control room. Some of the applications that have been introduced through the POC facility at PG&E include model validation metrics, post event analytics, oscillatory stability monitoring, islanding detection and resynchronization, and system disturbance characterization which are all now available for System Planning, Operational Engineering, and real-time operation use. The paper also describes some of the approaches taken to overcome hurdles that were identified early on towards the technology adoption. These include improving PMU data quality, providing operator guidance on the new synchrophasor applications, and having an effective training program for operators.

A major component for large scale deployment strategy of Synchrophasor systems is roadmap to engage various lines of business. One of the key components to successful integration of large scale deployment is strategy for life cycle infrastructure and maturing internal core competency. To facilitate lines of business participation, a Proof of Concept simulation facility is invaluable to both internal developments as well as in working with manufacturing. GE and Pacific Gas and Electric (PG&E) have been collaborating and advancing for almost a decade on augmenting the existing PMU measurement-based analytics within the synchrophasor platform with model-based analysis and

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simulation capabilities towards shaping the future Energy Management Systems (EMS) and Dispatcher Training Simulator (DTS).

KEYWORDS

Phasor Measurement Units (PMUs), Synchrophasors, Wide Area Monitoring Systems (WAMS), next-generation Energy Management System (EMS), next-generation Dispatcher Training Simulator (DTS).

INTRODUCTION

Through a cost-shared effort and partnership between some US utilities and the US Government, in excess of $8 billion has been invested towards further grid modernization. As a result, twelve projects deployed Phasor Measurement Units (PMUs) and synchrophasor applications resulting in an order of magnitude growth in PMU deployment from an initial 200 research grade devices to nearly 2000 production grade devices and communications infrestructure in North America by 2014 [2]. In many cases, redundant measurements installed in the substation to ensure data availability at the control center.

In 2008, Novosel, Madani, et al [2] advocated for implementation of synchrophasor technology, coordinated effort among utilities, ISOs and other entities, a bottom-up approach from utilities in defining the needs, a top-down approach from regulators and coordinators to define an integrated infrastructure, and the need for vendors to productize the applications that had been mostly in experimental stages. "*Well-planned, system-wide synchronized measurement deployment infrastructure is necessary to take full advantage of the technology.*"

Pacific Gas & Electric, a cost share smart grid advancement partner with the DOE, has long recognized the value proposition offered by synchrophasor technology and continues to work with the industry and its manufacturing partners to advance the technology both in maturing deployed solutions as well as future benefits to be realized from the investment. Several objectives have been achieved as part of the investment project and the use of POC facility:

- Internal stakeholder participation across all lines of business
- Multi-vendor active participation and collaboration
- Academic participation and research
- Industry and National Institutions participation
- Cognitive Task Analysis
- State of the art Proof of Concept (POC) facility to test various aspects of utility representative, redundant integrated system which otherwise will be very expensive and time consuming to test in the field

As part of the value added and in order to support advancements of Synchrophasor applications with gradual introduction of tools for operational use, PG&E has created a follow-on realization project with new solutions being tested for the future grid operation challenges as high-lighted by Giri and Parashar [3]. The path to future grid is through evolution of current SCADA-based "steady-state" Energy Management System (EMS) to a PMU-based "dynamic" EMS. In this paper, the authors present the latest developments at PG&E that help them move towards operationalizing synchrophasor technology in the control room including PMU-based voltage stability management and hybrid state estimation and unified visualization across both PMU and traditional SCADA/EMS information. Some of the obstacles that have been overcome in doing so have included operator guidance tools on synchrophasor "measurement-based" applications, training environment that can simulate realistic conditions for operator training, and improved data quality.

OPERATOR GUIDANCE ON SYNCHROPHASORS APPS

Synchrophasor systems offer a variety of information both post event and in real-time. In many cases, the information is new findings and therefore time is needed to understand the phenomenon before any action is taken. One of the major challenges to accept new synchrophasor-based monitoring tools into the control room is the expectation of an actionable operational decision, solely based on PMU data, to mitigate a potential dangerous situation. Through a hybrid approach, synchrophasor measurement-based analytics are augmented with well-known network model-based sensitivity calculations to perform "what-if" predictions and to suggest corrective control actions.

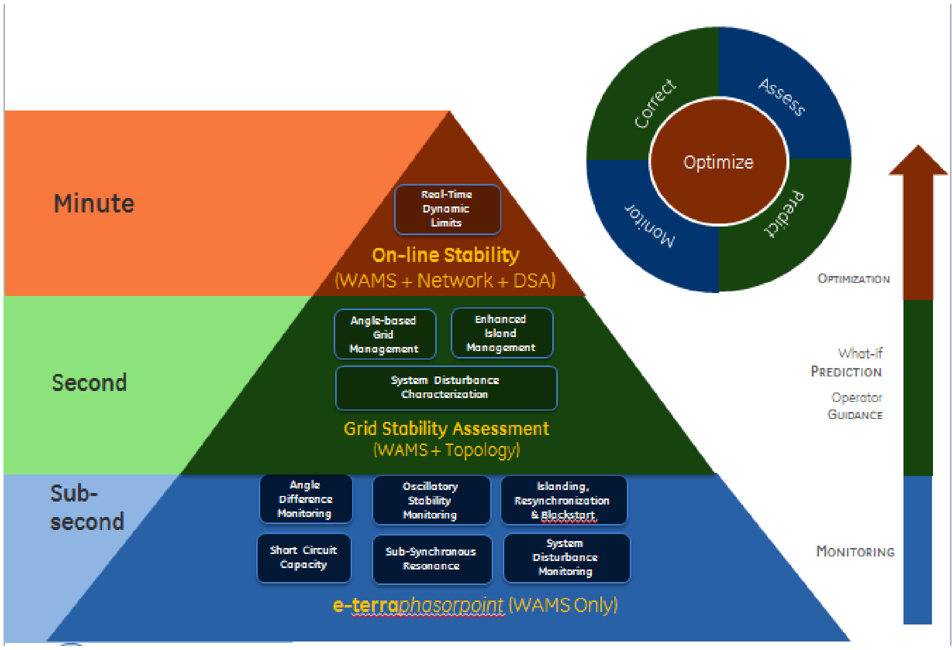

Fig. 1. Hybrid WAMS-EMS paradigm towards predictive and corrective capabilities in the control room.

Some of the initial open loop (human part of the decision) applications of control actions, based on PMU, likely will be in the form of adjusting generation to achieve desired operational angle between two systems in order to parallel the system. Other initiatives include hybrid model-based contingency analysis. Using angular separation monitoring as an example, Line Outage Distribution Factors (LODF) allow computation of the post-contingency angles for a pre-defined set of outage scenarios, akin to computing MW flow changes. Then model-based sensitivity analyses can provide a quantitative ranking of operator actions (such as raise or lower generation) in order to reduce the angular separation and restore them to acceptable limits. Such intelligence can now be made available to operators for PMU-based angular separation monitoring.

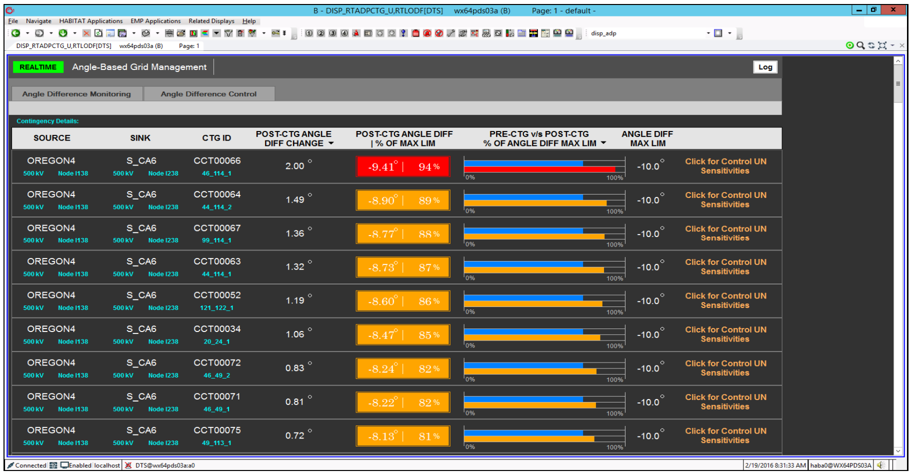

Fig. 2. Angular separation ranking – pre and post contingency.

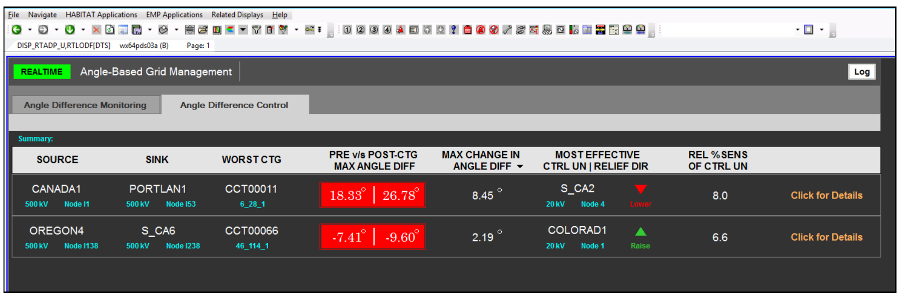

Fig. 3. Sensitivity-based recommendations for reducing angular separation.

Similarly, the WAMS Islanding analytics which quickly detect an islanding condition, can be augmented to analyze network topology to identify the specific island boundaries, provide an assessment of the available resources within each island to stabilize the island, and recommend possible options for subsequent resynchronization of the grid.

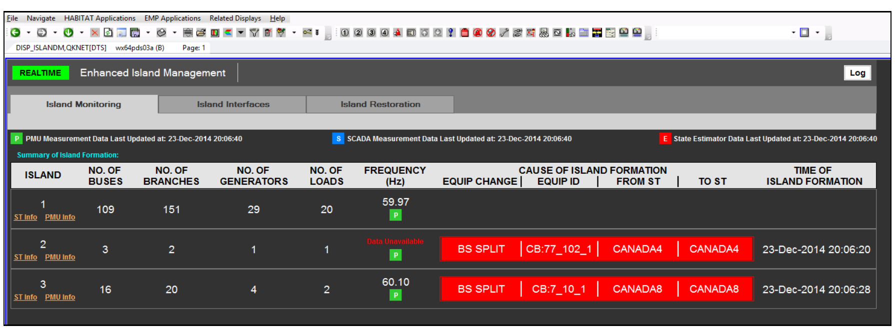

Fig. 4. Islanded regions and associated root cause.

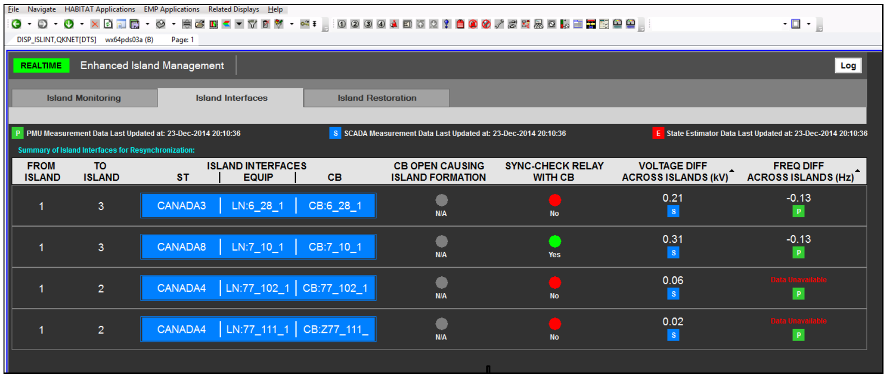

Fig. 5. Operator recommendations for resynchronizing the grid.

A number of additional sets of requirements are to be in place for automated closed loop type applications including business case development, data reliability, a much deeper understanding of the phenomenon observed as result of PMU data and accuracy of the information. For example, a 99% measured data accuracy may not be ideal for the specific closed loop application even in the case of a strong business case.

TRAINING ENVIRONMENT

Operators have traditionally been used to looking at a steady state view of the grid. With synchrophasor technology introducing dynamic performance indicators metrics such as oscillation damping and phase angles require enhanced training is needed. Advanced training environments and programs are needed for a more comprehensive in-depth sets of hands-on-deck training using synchrophasor systems.

Such training simulators can be build based on the original foundations for training simulators in operation fllor. For example, GE, in collaboration with Pacific Gas & Electric (PG&E) and Powertech Labs, has been developing a Dynamic Dispatcher Training Simulator (DynamicDTS) which augments the powerflow engine within the traditional DTS with a transient stability engine to generate synthetic PMU data based on dynamic simulations, which then drive the downstream applications, as shown in Figure 6.

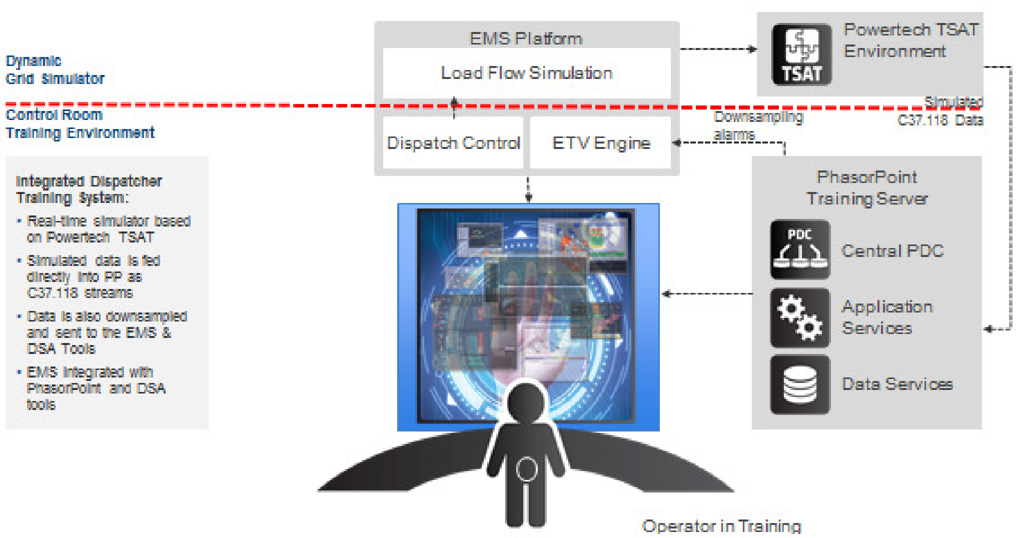

Fig. 6. DynamicDTS display (opening a breaker to create an islanding condition resulting in frequency and phase angle separation).

The DynamicDTS has proven to be an effective tool in creating training scenarios to highlight the information associated with each of the different synchrophasor application.

DATA QUALITY IMPROVEMENTS

One of the major hurdles in synchrophosor adoption has been poor data quality. Several utilities are adopting processes in place for validating the PMU measurements against other data sources such as State Estimator results. Entities such as PG&E with a denser PMU coverage, are looking at utilizing a synchrophasor-only State Estimator (also known as Linear State Estimator or LSE) both in real-time and study modes to detect and correct for measurement errors. This approach essentially validates the measurements against the network model to ensure that they satisfy Kirchhoff's laws – measurements with high residuals imply that there's a problem with either the measurement or the model, and requires further investigation. The LSE methodology has shown to be very effective in detecting and correcting for CT or PT calibration issues, as well as phase angle offset issues due to phase wiring errors or delta-wye transformation [4].

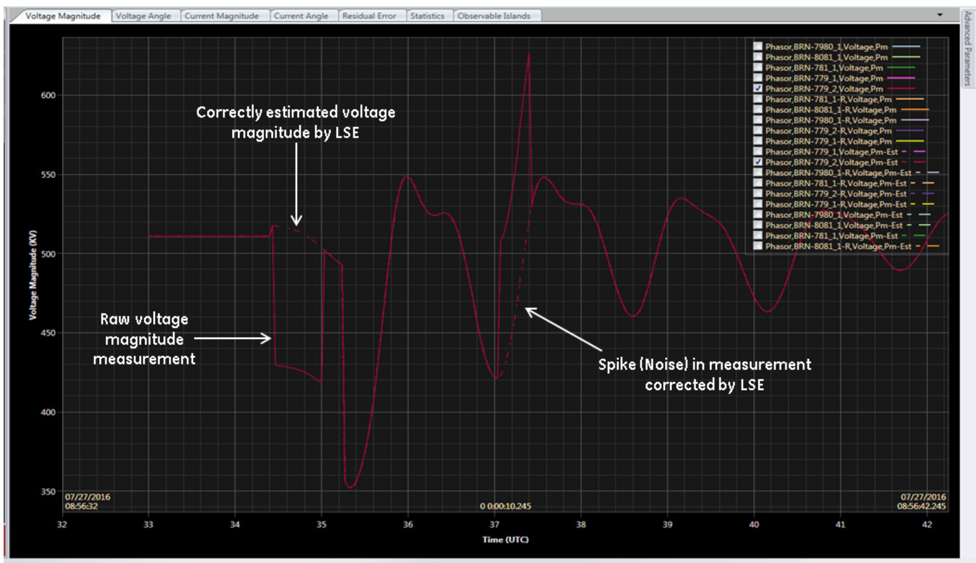

Fig. 7. Voltage magnitude errors corrected by LSE (solid line is the measured angle, and the dotted line is the LSE estimated angle).

HYBRID VOLTAGE STABILITY MANAGEMNT

Avoiding voltage collapse is critical to utility operations, and is certainly of interest to the power industry. Traditionally, model based voltage stability assessment tools are used. These tools (e.g. Powertech's VSAT) have certain advantages such as handling contingencies but they tend to take more execution time (of the order of minutes). PMU-based voltage stability applications such as Real-time Voltage Instability Indicator (RVII) offer the advantage of being fast (e.g. at 30 times per second) in monitoring the voltage stability margin in real-time [5]. Furthermore, by augmenting RVII's measurement-based monitoring capabilities with model-based predictive analysis from the Voltage Security Assessment Tool (VSAT) to assess changes in RVII's voltage stability margins to discrete events such as contingencies or generator reactive limits being reached, the user is able to introduce "what if" capabilities to RVII approach.

PG&E's POC facility along with its Real-time Digital Simulator (RTDS) is used to validate the RVII approach along with the predictive capabilities by emulating those outages.

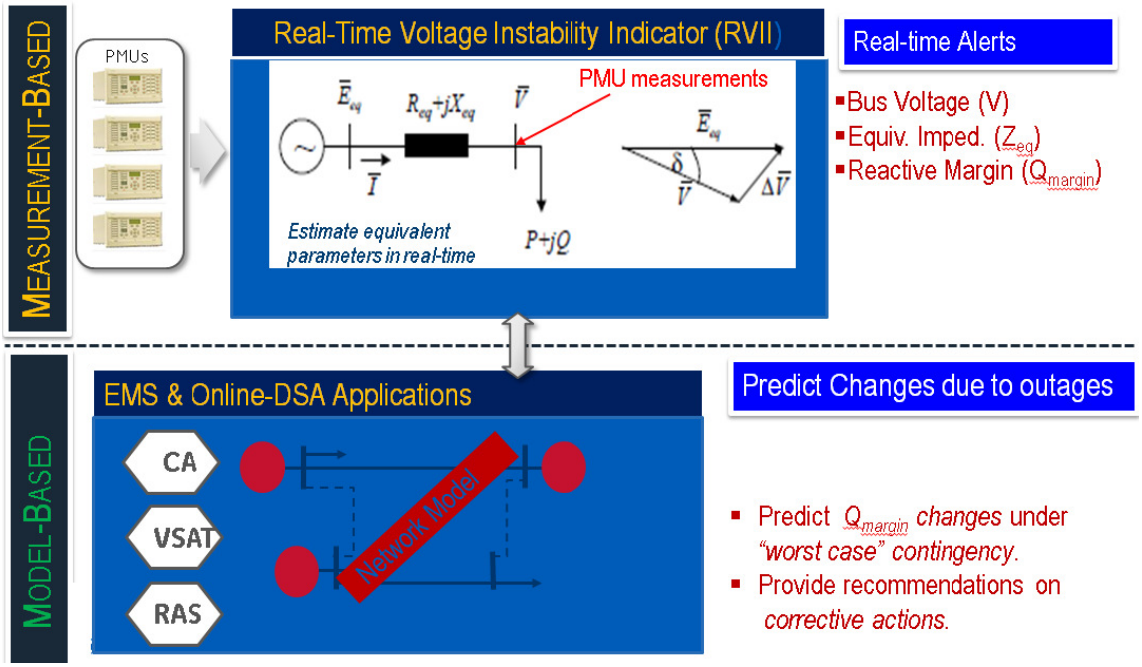

Fig. 8. Hybrid Voltage Stability Management approach

SUMMARY

Synchrophasor measurements are becoming ubiquitous as modern day field devices such as relays and disturbance fault recorders have the ability to stream synchrophasor measurements. Good data quality is critical to the successful adoption of the technology, which can only be achieved through a well-designed end-to-end redundant architecture with dedicated IT support staff and processes to manage these systems, similar to existing EMS. Approaches such as Linear State Estimation are effective ways to detect data quality errors and potentially correct them. New and enhanced training tools are important enablers for open-loop actions. As synchrophasor technology becomes mainstream, it is shaping the next generation EMS (and DTS), and therefore tighter integration between synchrophasor applications with traditional EMS functions is equally important to provide the necessary predictive capabilities and corrective guidance that operators expect from their EMS. Based on the already created physical infrastructure and new genre of hybrid WAMS-EMS applications such as the ones described, situational awareness can be transformed into situational intelligence which will eventually pave the way to wide area closed-loop control.

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