Testing and Validation of Phasor Measurement Based Devices and Algorithms

Final Project Report

Power Systems Engineering Research Center

Empowering Minds to Engineer the Future Electric Energy System
Testing and Validation of Phasor Measurement Based Devices and Algorithms

Final Project Report

Project Team

Anurag K Srivastava, Project Leader
Saugata S Biswas, Graduate Student
Washington State University

A. P. Sakis Meliopoulos
Evangelos Polymeneas, Graduate Student
Yonghee Lee, Graduate Student
Georgia Institute of Technology

PSERC Publication 13-44

September 2013
For information about this project, contact

Anurag K Srivastava, Project Leader
Assistant Professor, The School of Electrical Engineering and Computer Science
Director, Smart Grid Demonstration and Research Investigation Lab (SGDRIL)
Energy Systems Innovation Center (ESIC)
Washington State University
355 Spokane St, Pullman, Washington 99164-2752
Phone: 509-335-2348
Fax: 509-335-3818
Email: asrivast@eecs.wsu.edu

Power Systems Engineering Research Center

The Power Systems Engineering Research Center (PSERC) is a multi-university Center conducting research on challenges facing the electric power industry and educating the next generation of power engineers. More information about PSERC can be found at the Center’s website: http://www.pserc.org.

For additional information, contact:

Power Systems Engineering Research Center
Arizona State University
527 Engineering Research Center
Tempe, Arizona 85287-5706
Phone: 480-965-1643
Fax: 480-965-0745

Notice Concerning Copyright Material

PSERC members are given permission to copy without fee all or part of this publication for internal use if appropriate attribution is given to this document as the source material. This report is available for downloading from the PSERC website.

© 2013 Washington State University and Georgia Institute of Technology
All rights reserved.
Acknowledgements

This is the final report for the Power Systems Engineering Research Center (PSERC) research project titled “Testing and Validation of Phasor Measurement Based Devices and Algorithms” (project S -45). We express our appreciation for the support provided by PSERC’s industry members and by the National Science Foundation under the Industry / University Cooperative Research Center program.

We wish to thank our industry advisors for their support and help: Jeff Fleeman (American Electric Power), Evangelos Farantatos (Electric Power Research Institute), Floyd Galvan (Entergy), Jim Kleitsch (American Transmission Company), Xiaochuan Luo (ISO New England), Bill Middaugh (Tri-state Generation and Transmission), Reynaldo Nuqui (ABB), George Stefopoulos (New York Power Authority), and Sanjoy Sarawgi (American Electric Power).

Special thanks to Southern California Edition to provide internship opportunity related to PMU performance testing to Saugata Biswas. We would also like to thank graduate students Jeong Kim and Hyojong Lee as well as an undergraduate student Rory Beckstorm at Washington State University for their help in PMU and PDC testing. Additionally, we are grateful to Schweitzer Engineering Lab, General Electric, ALSTOM, ERLphase, PONOVO and RTDS, Inc. for their support.
Executive Summary

For upgrading the traditional electric power system to a smart power grid, it is essential to make several enhancements at various levels of operation and control, which includes the integration of Intelligent Electronic Devices (IEDs), synchrophasor devices, advanced communication infrastructure and efficient monitoring and controlling algorithms that would make optimum use of these devices. The event of August 14, 2003 blackout in the north eastern United States and parts of Canada that affected almost 50 million people emphasized the need for real time situational awareness, and thus advocated the use of synchrophasor devices in the power system. PMUs enable the wide area visualization of a power system in real time by capturing high speed time-stamped snapshots in the form of voltage and current phasors, frequency and rate of change of frequency at the rate of up to 120 frames/second. This kind of “time stamping” allows the measurements from different geographical locations to be time-aligned or “synchronized”, thus providing a precise and comprehensive view of the entire system. Synchrophasor technology enables a good indication of the status or condition of power grid in real time. However, before putting the smart devices and algorithms in use in the actual power grid, it is of utmost importance to test and validate their capabilities as well as their accuracy.

The motive is to ensure high accuracy of measurements from synchrophasor devices and the validation of developed algorithms utilizing synchrophasors, under different operating scenarios of the power system. This research project report mainly focuses on following goals, (a) testing and validation of synchrophasor devices; b) testing of phasor based voltage stability and state estimation applications utilizing a real time hardware-in-the-loop (HIL) test bed; and (c) utilization of PMUs for advanced protection schemes with emphasis on dynamic protection algorithms for transformers.

To achieve these goals, the testing facility based on Real Time Digital Simulator (RTDS) at Washington State University (WSU) and WinIGS-T at Georgia Institute of Technology (GIT) were both upgraded to perform testing of synchrophasor devices and applications. For synchrophasor device testing, test systems and also library of test conditions were developed to simulate system scenarios as specified in IEEE C37.118.1 standard. Testing for number of phasor measurement units (PMUs) have been performed against modeled standard PMU. Testing for software and hardware phasor data concentrators (PDCs) have been also performed against limited number of performance criterion. For real time testing and validation of phasor based applications, we focused on voltage stability, state estimators and dynamic protection algorithms for transformers. These applications were simulated in lab environment for some example algorithms to check performance and find potential problems before installing in industry grade power system.

Synchrophasor Device Testing

Test conditions for PMU’s include a) nominal and off-nominal frequency; and b) with and without harmonics, under balanced steady state conditions while magnitude, phase angle and frequency are changed within ranges as specified in the IEEE C37.118.1 standard. For dynamic testing, test conditions include, a) magnitude, angle and frequency
step change; b) frequency ramp change; and c) amplitude, phase and frequency modulation.

The tests reveal that the performance of the different PMUs tested in lab are excellent under steady state conditions and near nominal frequency. The tested PMUs meet the IEEE Standard permissible error of total vector error. However under dynamic and off nominal frequency there is great variability among the various manufacturers and the errors can be quite high. All performance data do not identify the specific device tested. Also, total vector error (TVE) for current is generally higher than voltage TVE and TVE is not the same for each phase. Frequency error (FE) and rate of change in frequency (ROCOF) error (RFE) is within limits for most of the cases. For dynamic testing example of one specific PMU, magnitude step change and angle step change meets the requirement of response time and peak overshoot but not the delay time. For frequency step change, requirements for frequency response time and peak overshoot are met but not the ROCOF response time and delay time. For, frequency ramp change, requirements are not met for FE and RFE. For, amplitude phase and frequency modulation test, PMU fails all performance criterion testing.

Test results for PDC show that the tested PDCs shows satisfactory response in aligning data and data validation test was also successful for different durations and reporting rate of data streaming, collection and archival. There is no data loss, if PMU directly streams data to a PDC without going through a complex communication network. However, when the PMU sends data to the PDC via communication networks, there is considerable data loss. Data latency, data rate conversion, format conversion, phase/ magnitude compensation were found satisfactory for tested PDC’s.

**Synchrophasor Application Testing**

The test bed was modified to perform real time testing of voltage stability algorithms using real time controllers and real time digital simulators. Voltage stability algorithm tested in lab shows performance as expected for line outages and change in loading conditions. State estimation algorithm is dynamic and perform very well with transformer inrush current, over-excitation and with fault conditions.

The setting-less protection approach based on dynamic state estimation for the 3-phase transformer has been proven to be a reliable method to protect the transformer against internal faults. It was shown that the relay does not trip during normal operating conditions or faults outside the protection zone. On the other hand, a trip is decided during the internal fault. The simulation results verify the theoretical analysis. The computation time needed is within the requirements of the data acquisition scheme.

Outcomes of this project include (a) Set of standard accuracy and performance tests for PMUs; (b) An enhanced test bed to demonstrate operation of phasor devices for research/educational purposes; (c) Evaluation of PMU based applications including voltage stability and state estimation in real time; and (d) Better dynamic protection algorithm for transformer.
Performance results reported here for PMU and PDC can be used to guide evolution of the standards and to provide insight for manufacturer. Test results also shows need for additional algorithms to filter out bad data for applications related to transients and dynamics as well as real time control. Dynamic protection algorithms for transformer protection can be incorporated in new relays with PMU capability.

**Project Publications:**


[7]. A. P. Meliopoulos, E. Polymeneas, Zhenyu Tan, Renke Huang, and Dongbo Zhao, “Advanced Distribution Management System”, *IEEE Transactions on Smart Grid*, accepted.


**Student Theses:**

