Adaptive and Intelligent PMUs for Smarter Applications

Executive Summary

Power Systems Engineering Research Center

Empowering Minds to Engineer
the Future Electric Energy System

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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.

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Performance of Phasor Measurement Units (PMUs) varies with operating conditions such as dynamic system states, harmonics, off-nominal frequency and changes due to load changes and/or faults. Phasor based applications may utilize only part of the PMU measurements like frequency, voltage magnitude or angles. Accuracy of these specific measurements depends on estimation and filtering algorithms within PMU, which can be switched between different algorithms to adopt with specific applications and operating conditions for higher performance. The PMU can self-report critical data quality information such as estimation error and GPS status using user-defined bits to provide better decision support for operators.

Distributed applications using PMU data may require some of the computation to be done within PMU. Data management can be done in intelligent manner to minimize the computational and communication burden centrally as well as to enable enhanced applications. Additionally, user defined bits can be used in flexible and intelligent manner to realize enhanced capability of PMU for smarter applications. PMU data quality and interchangeability of PMU with changing applications is another important issue.

This project focuses on all the above aspects to develop 'adaptive' and 'intelligent' PMU for smarter applications and believes that 'one PMU does not fit all applications and all operating conditions'. In this project, we have developed several versions of advanced PMU with different features: the adaptive PMU, the standard PMU, virtual PMUs and the distribution PMU. In addition, improved testing methods to characterize the accuracy of these PMUs are also reported.

For the adaptive PMU algorithm, wavelet transform (WT) based phasor estimation is proposed as an alternative estimation technique for dynamic system condition like off-nominal frequency. The system frequency is updated by WT based estimation of target frequency. Also, multiple filtering techniques have been developed to provide options for different operating conditions. Switching techniques is proposed to identify system-operating conditions and choose suitable estimation algorithm within PMU. The standard PMU algorithm performs discrete Fourier transform (DFT) utilizing a variable time window so as the frequency changes the integration interval always contains an integer number of cycles. Thus, spectral leakage and other known errors of the Fourier transform for a signal of changing frequency are eliminated. We have also developed a virtual PMU using the DFT based Standard PMU algorithm. The performance of Standard PMU algorithm is evaluated with variable sampling rates and several different interpolation methods. Performance results are provided in the report for all these PMUs using PMU Performance Analyzer (PPA) and WinXFM platform as well as upgraded test beds. Distribution PMU is designed as a single-phase low cost PMU using National Instruments Platform.

Synchrophasor data quality is another important issue. PMU data can be dropped by communication system, have high noise, or have errors attributable to GPS signal errors. We had access to industry provided field PMU data and developed techniques to identify defective synchrophasor data using statistical techniques.

This work is opening up various possibilities for more intelligent applications as well as more intelligent automation of power system functions. One of the applications is dynamic state

estimation based protection, a.k.a. setting-less protection. Experimental results show that the setting-less protection method provides better performance than traditional protective schemes.

The report highlights challenges of using synchrophasor data collected during power system equilibrium state transitions to understand and characterize dynamic behavior. Interoperability and interchangeability is an important issue for intelligent PMUs. We propose an interoperability standard for intelligent PMUs in terms of power device model data exchange.

This project resulted in following publications:

[1] Pinte, Bogdan; Michael Quinlan, Andy Yoon, Karl Reinhard, and Peter W. Sauer. "A One-Phase, Distribution-Level Phasor Measurement Unit for Post-Event Analysis", *Proceedings, Power Engineering Conference Illinois*, Champaign, IL, February, 2014.

[2] Kirihara, Kenta; Karl E. Reinhard, Andy K. Yoon, and Peter W. Sauer. "Investigating Synchrophasor Data Quality Issues", *Proceedings, Power Engineering Conference Illinois*, Champaign, IL, February, 2014.

[3] Pinte, Bogdan; Michael Quinlan, and Karl Reinhard. "Low Voltage Micro-Phasor Measurement Unit (μPMU)", *Proceedings of the Power Engineering Conference*, Champaign, IL, February, 2015.

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[12] Meliopoulos, A.P. Sakis. "Distributed Dynamic State Estimator Enables Seamless DSA," *Proceedings of the IEEE-PES 2014 General Meeting*, Washington, D.C., July 27-31, 2014.

[13] Liu, Yu; A.P. Sakis Meliopoulos, Rui Fan, and Liangyi Sun. "Dynamic State Estimation Based Protection of Microgrid Circuits," *Proceedings of the IEEE-PES 2015 General Meeting*, Denver, CO, July 26-30, 2015.

Student Theses:

[1] Kirihara, Kenta. "*Big Data in Power Systems: A Statistical Approach on Synchrophasor Application,"* University of Illinois at Urbana-Champaign, M.S. in Electrical and Computer Engineering, July 2015.

[2] Pinte, Bogdan. "*Development and Implementation of an Open-Box Distribution-Level Phasor Measurement Unit,"* University of Illinois at Urbana-Champaign, M.S. in Electrical and Computer Engineering, May 2015.

[3] Quinlan, Michael. "*Development and Deployment of a Residential Voltage Level Phasor Measurement Unit*," University of Illinois at Urbana-Champaign, M.S. in Electrical and Computer Engineering, May 2015.

[4] Saugata Biswas. "*Synchrophasor Based Voltage Stability Monitoring and Control of Power Systems*", Washington State University, Ph.D., September 2014.