



Sparse Sensing Methods for Model-Free Sensitivity Estimation and Topology Change Detection using Synchro-Phasor Measurements

Final Project Report

S-59

Power Systems Engineering Research Center

*Empowering Minds to Engineer
the Future Electric Energy System*



Sparse Sensing Methods for Model-Free Sensitivity Estimation and Topology Change Detection using Synchro-Phasor Measurements (S-59)

Final Project Report

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Power Systems Engineering Research Center

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Executive Summary

State estimation, and health monitoring for general situational awareness at a power system control center, inevitably employs a mix of a priori information, based on system model and parameter data, and observations in the form of measurement data. In traditional power systems applications, when SCADA systems provided only low-bandwidth, unsynchronized measurement data to a control center, observations and a priori information typically contributed on nearly equal footing in applications such as state estimation and topology error identification. Today, the availability of high-bandwidth, time-synchronized PMU data shifts this balance, creating a much larger role for observations, and reducing the need for full model information, thereby opening the door to much faster time-scale estimation. However, rather than replacing existing state estimation tools and the applications that depend on them, the techniques developed in this project seek to provide much higher bandwidth estimation, to “fill in” situational awareness between slower, periodic state estimator updates. The particular algorithms developed focus on two applications: (A1) fast time-scale, dynamic detection and identification of network topology changes; and (A2) PMU measurement-based, (nearly) “model-free” estimation of the power flow Jacobian. The report is divided into four parts: Parts I-III cover the work conducted under Application A1, whereas Part IV covers the work conducted under Application A2.

Part I: Quickest Change Line Outage Detection and Identification

In this part, we propose a framework for detection and identification of system topological changes in near real-time that utilizes the statistical properties of electricity generation and demand, which are assumed to be known. Instead of relying on offline models as with traditional methods, the proposed method is model-free, and exploits the high-speed synchronized measurements provided by phasor measurement units (PMUs). In this framework, a statistical quickest change algorithm is applied to the voltage phase angle measurements collected from PMUs to detect the change-point that corresponds to the system topology change instant. An advantage of this algorithm is that the operator also has full control over the tradeoff between detection delay and false alarm rate. In order to lend support for the work conducted, case studies are done through simulations on standard IEEE test systems

Part II: PMU Placement via Multinomial Logistic Regression

In this part, we also consider the problem of identifying a single line outage in a power grid by using data from PMUs. When a line outage occurs, the voltage phasor of each bus node changes in response to the change in network topology. Each individual line outage has a distinctive “signature,” and a multinomial logistic regression (MLR) classifier can be trained to distinguish between these signatures reliably. We consider first the ideal case in which PMUs are attached to every bus. We then describe techniques from regularized optimization for placing PMUs selectively on a subset of buses, with the subset being chosen to allow discrimination between as many outage events as possible. Experimental results with synthetic 24-hour demand profile data generated for several IEEE test systems.

Part III: An Observer-Based Approach of Topology Change Estimation

In this part, the goal here is identification of topology errors from PMU data, exploiting dynamic characteristics of the power systems response, while being able to discriminate topology errors from bad data. Types of topology errors common in Power Systems include incorrect status of line switches, transformer tap settings, shunt compensation, etc. The focus here is on line switching events. In this work, the estimation of line switching events from measured errors is sought by concentrating the disturbance input due to the line outage(s) into an invariant subspace of the state matrix of the Luenberger observer. This formulation has the advantage of allowing operation of multiple observers in parallel, facilitating simultaneous monitoring of multiple line switching events.

Part IV: Measurement-Based Estimation of the Power Flow Jacobian

In this part, we propose a measurement-based method to compute the power flow Jacobian matrix, from which we can infer pertinent information about the system topology in near real-time. A salient feature of our approach is that it readily adapts to changes in system operating point and topology; this is desirable as it provides power system operators with a way to update, as the system evolves, the models used in many reliability analysis tools. The method uses high-speed synchronized voltage and current phasor data collected from phasor measurement units to estimate entries of the Jacobian matrix through linear total least-squares (TLS) estimation. In addition to centralized TLS-based algorithms, we provide distributed alternatives aimed at reducing computational burden. Through numerical case studies involving standard IEEE test systems, we illustrate the effectiveness of our proposed Jacobian-matrix estimation approach as compared to the conventional model-based one.

Project Publications:

The work reported in the publications below was supported in part by project S-59.

Journal Papers:

- [J1] T. Kim, and S. J. Wright, "PMU Placement for Line Outage Identification via Multiclass Logistic Regression," *IEEE Transactions on Smart Grid*, to appear.
- [J2] Y. C. Chen, J. Wang, A. D. Domínguez-Garcia, "Measurement-Based Estimation of the Power Flow Jacobian Matrix," *IEEE Transactions on Smart Grid*, vol. 7, no. 5, 2507-2515, September 2016.
- [J3] Y. C. Chen, T. Banerjee, A. D. Domínguez-Garcia, and V. V. Veeravalli, "Quickest Line Outage Detection and Identification," *IEEE Transactions on Power Systems*, vol. 31, no. 1, pp. 749-758, January 2016.

Conference Papers:

- [C1] G. Rovatsos, X. Jiang, A. D. Domínguez-Garcia, and V. V. Veeravalli, "Comparison of Statistical Algorithms for Power System Line Outage Detection," in *Proc. of IEEE International Conference on Acoustics, Speech, and Signal Processing*, Shanghai, China, March 2016.

Student Theses:

- [T1] X. Jiang, *Real-Time Power System Topology Change Detection and Identification*, Ph.D. Thesis, University of Illinois at Urbana-Champaign, August 2016.
- [T2] S. Acharya, *Topology Error Estimation in Power System Dynamic Models*, MS Thesis, University of Wisconsin-Madison, December 2015.
- [T3] T. Kim, *Optimization Approaches for Reliable Operation of Electric Power Systems*, Ph.D. Thesis, University of Wisconsin–Madison, July 2015.
- [T4] Y. C. Chen, *Measurement-Based Tools for Power System Monitoring and Operations*, Ph.D. Thesis, University of Illinois at Urbana-Champaign, December~2014.