



Input-Output Metrics for the Power-Grid's Swing Dynamics

Final Project Report

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Power Systems Engineering Research Center
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the Future Electric Energy System*



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Executive Summary

Part 1: Online Transfer Function Estimation and Control Design Using Ambient Synchronphasor Measurements

Power systems around the world are undergoing major changes as we transition from fossil-fuel dominated generation to intermittent renewable generation sources. Moreover, power grids are having to deal with extreme weather events and unforeseen operating conditions. In these circumstances, controller designs which are based on offline studies and detailed physical models may not be able to adjust to sudden changes in system operating conditions. This report proposes an adaptive control design framework for damping inter-area oscillations in power systems. The design is entirely based on ambient synchronphasor measurements and does not require detailed physical system models. The proposed framework consists of three components, namely, input-output transfer function estimation, channel selection, and feedback control implementation. For the first part, we propose a simple yet effective novel estimation algorithm in the frequency domain to identify low-order transfer functions in pre-specified frequency ranges between the measured input and output data using ambient synchronphasor measurements. In the second part, based on the identified transfer functions, the joint controllability-observability (JCO) of all identified channels is estimated and suitable control candidates for damping the target inter-area mode are selected. Finally, an appropriate lead-lag controller is designed using a classical frequency-domain method to improve the damping of a dominant oscillatory inter-area mode. Since ambient data is used in the analysis, the selected channel as well as the designed controller parameters can be updated online whenever the system operating point changes resulting in an efficient adaptive controller. The effectiveness of the proposed framework is illustrated by implementing it on the two-area Kundur test system.

The research developed in this project is partially described in the following paper which is under review.

Part II: Parametric Dependence Analysis and Channel Preserving Model Reduction

The design of wide-area controllers for the bulk power grid requires characterization of input-output channels in swing-dynamics models. However, the large variability in operating conditions in the modern grid makes the evaluation of channel transfer properties challenging. In this study, we examine how transfer functions in the classical swing dynamics model depend on network model parameters (the topology of line susceptances, generator inertias, dampings) and the channel location, focusing particularly on determining conditions under which the transfer function is guaranteed to be minimum phase or conversely nonminimum phase. In particular, graph-theoretic conditions as well as numerical bounds on network model parameters are obtained, that either preserve minimum-phase dynamics or yield non-minimum-phase behaviors.

Project Publications:

- [1] M. Hatami, K. Koorehdavoudi, H. Wajid, V. Venkatasubramanian, P. Panciatici, F. Xavier, and G. Torresan, "Online Transfer Function Estimation and Control Design Using Ambient Synchronphasor Measurements", in review.

- [2] K. Koorehdavoudi, S. Roy, T. Prevost, F. Xavier, P. Panciatici, and V. Venkatasubramanian, “Input-output properties of the power grid’s swing dynamics: Dependence on network parameters,” IEEE Conference on Control Technologies and Applications (IEEE CCTA), Hong Kong, 2019.