



Load Model Complexity Analysis and Real-Time Load Tracking (S-60)

Final Project Report

S-60

Power Systems Engineering Research Center

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Project Team

Hao Zhu, Project Leader
Thomas Overbye
University of Illinois at Urbana-Champaign

Bernie Lesieutre
University of Wisconsin-Madison

Graduate Students

Siming Guo
University of Illinois at Urbana-Champaign

Kaiqing Zhang
University of Illinois at Urbana-Champaign

PSERC Publication 17-01

March 2017

For information about this project, contact

Hao Zhu
University of Illinois at Urbana-Champaign
Department of Electrical and Computer Engineering
4056 ECE Building
306 North Wright St. Urbana, IL, 61801
haozhu@illinois.edu

Power Systems Engineering Research Center

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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

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Acknowledgements

This is the final report for the Power Systems Engineering Research Center (PSERC) research project titled “Load Model Complexity Analysis and Real-Time Load Tracking” (project S-60). We express our appreciation for the support provided by PSERC’s industry members and by the U.S. Department of Energy Bonneville Power Administration (BPA) under the Technology Innovation Project program. Siming Guo and Thomas Overbye were partially supported by the BPA Project TIP357.

The authors also thank the industry advisors for this project: Mirrasoul Mousavi (ABB); Robert O’Keefe (AEP); William Kouam Kamwa (AEP); Curtis Roe (ATC); Damien Sommer (ATC); Ran Xu (BPA); Aftab Alam (California ISO); Anish Gaikwad (EPRI); Alan Engelmann (Exelon); Chaitanya Baone (GE Research); Slawek Szymanowski (ISO-NE); Marissa Hummon (National Renewable Energy Lab); George Stefopoulos (NYPA); and Scott Jordan (SPP).

Executive Summary

Power system dynamic simulations and transient stability studies vitally depend on the accuracy of the load models. However, it is widely recognized that the monitoring capability for loads is insufficient while the accuracy of load models has not been fully investigated. Meanwhile, the analysis on the adequacy or necessity of existing dynamic composite load models is left open in the literature. This project aims to tackle these challenges by analyzing the complexity trade-off of the load models used for studying the increasingly critical fault-induced delayed-voltage recovery (FIDVR) events. Real-time and non-intrusive estimation of the load models are also pursued in this project, by leveraging high-resolution and high-bandwidth data even available within distribution feeders. This project has successfully developed a software tool for grid operators to perform measurement-based load modeling using the WECC composite load model (CMPLDW) structure. The report is presented in two parts.

Part I: Model Complexity Analysis and Improved Parameter Estimation for Dynamic Load Models

Transient stability analysis is becoming increasingly important for power systems engineers and researchers. Accurate dynamic models are required, but dynamic load modeling by fitting the input-output measurements during fault events is an area of weakness. For example, the WECC composite load model (CMPLDW) has been developed recently as an improvement to existing composite load models such as the complex load model (CLOD). The WECC CMPLDW has been developed to better represent fault-induced delayed-voltage-recovery (FIDVR) events, which are of increasing concern to electric utilities. However, the model nonlinearity and large number of parameters of the WECC CMPLDW model pose severe identifiability issues and performance degradation for the measurement-based load modeling approach using the classical nonlinear least-squares (NLS) objective.

This report will first present a general framework that can effectively analyze and visualize the parameter (in)sensitivity and dependency of complex dynamic load models with large numbers of parameters under FIDVR. The possible impact of these effects on the predictive ability of the model is also explored. Finally, we present an improved parameter estimation algorithm by better designing the NLS error objective using a regularized term according to *a priori* information on parameter values. Two different types of regularization techniques have been proposed. Effectiveness of our model sensitivity and dependency analysis, as well as the improved numerical performance of the proposed parameter estimation schemes, have been validated using both synthetic data and real measurement collected during FIDVR events. Albeit focused on the WECC CMPLDW and the CLOD model, the proposed approaches can be readily used for dynamic composite load modeling in general.

Part II: Non-intrusive Load Monitoring within Distribution Feeders

The FIDVR phenomenon is believed to be driven by the stalling of single-phase compressor motors, such as those in residential air conditioners and refrigerators. While CMPLDW was specifically designed to replicate this behavior, it may still be inadequate due to being a positive sequence model. Positive sequence simulations assume that sub-cycle phenomena are negligible,

but we show in both simulation and laboratory testing that this is not true for compressor motors. For an instantaneous voltage drop event, the motor is much more likely to stall if the event occurs at the moment of zero crossing as opposed to at a peak.

One aspect of load modeling that is often discussed but unsolved is the real-time updating of load model parameters on a daily or seasonal basis. In this work, we propose using harmonic information to monitor load composition. For example, the often-observed “rabbit ears” are characteristic of a power electronic load with a rectified front-end. Based on empirical data measured at an office building, we can observe that such loads are active during the day, but absent at night, which suggests an HVAC system run by variable frequency drives. Based on such analysis at the aggregate level, we can perform long term monitoring of load dynamics.

Project Publications:

K. Zhang, H. Zhu, and S. Guo, “Dependency analysis and improved parameter estimation for dynamic composite load modeling,” *IEEE Transactions on Power Systems*, 2017 (accepted). [Online] <http://ieeexplore.ieee.org/abstract/document/7728116/>

K. Zhang, S. Guo, and H. Zhu, “Parameter sensitivity and dependency analysis for the WECC dynamic composite load model,” *Proc. of 47th Hawaii Intl. Conf. on System Sciences (HICSS)*, Jan. 2017. [Online] <http://scholarspace.manoa.hawaii.edu/handle/10125/41540>

S. Guo, K. S. Shetye, T. J. Overbye, and H. Zhu, “Impact of measurement selection on load model parameter estimation,” *Proc. of Power and Energy Conference at Illinois (PECI)*, Feb. 2017.

Student Thesis:

S. Guo, “Improvements to power system dynamic load model parameter estimation,” Ph.D. dissertation, Dept. Elec. Eng., Univ. Illinois at Urbana-Champaign, Urbana, IL, 2017.