



Data-Driven Stability Analysis of IBR-rich Grids with hybrid EMT + Phasor Models

Final Project Report

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Power Systems Engineering Research Center
*Empowering Minds to Engineer
the Future Electric Energy System*



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Project Team

Amarsagar Reddy Ramapuram Matavalam, Project Leader

Vijay Vittal

Arizona State University

Subhonmesh Bose

University of Illinois, Urbana-Champaign

Graduate Students

Anirudh Chatti Venkata Sesha

Arnav Bagga

Giritharan Vijay Iswaran

Arizona State University

Boya Hou

University of Illinois, Urbana-Champaign

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For information about this project, contact:

Amarsagar Reddy Ramapuram Matavalam
Arizona State University
School of Electrical, Computer, and Energy Engineering
Tempe, AZ, 85287
Email: amar.sagar@asu.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: 480-727-2052

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Executive Summary

The large-scale integration of renewable variable generation and inverter-based resources (IBRs) significantly alters system responses to contingencies and fault events, affecting the system's ability to maintain stable operation under critical conditions. Insights from MISO's Renewable Integration Impact Assessment (RIIA) report indicate that when IBR penetration exceeds 30%, voltage and converter-driven stability concerns become prominent. This underscores the critical need to accurately model IBRs in stability studies to ensure a comprehensive understanding of system behavior under high renewable penetration.

With increasing levels of IBR integration, large disturbance stability analysis becomes essential for secure grid operation. Recent events have demonstrated the limitations of phasor domain simulations, emphasizing the need to incorporate full scale electromagnetic transient (EMT) simulations. This presents a major challenge for utilities and ISOs because IBRs are software defined grid components with much faster dynamics, operating on EMT time scales, compared to synchronous generators. In addition, capturing the detailed grid support functionalities of IBRs within full EMT models in large utility scale studies is both computationally demanding and time consuming.

To improve efficiency in stability studies, utilities are increasingly adopting hybrid EMT and phasor models, where IBRs are represented in the EMT domain while the remainder of the grid is modeled in the phasor domain. Although this approach reduces the computational burden, it lacks a unified framework for stability assessment. As a result, while these models can generate valuable data under transient conditions, there remains a pressing need for reliable methods to analyze the resulting multi-timescale data and ensure trustworthy stability evaluations.

To address these challenges, this work develops a data-driven transient stability assessment framework for IBR-rich grids represented by hybrid models. The approach integrates machine learning with fundamental system dynamics to characterize stability performance and localize instability causes during both planning and operations. By constructing a linear representation of the system in a lifted higher-dimensional space, stability analysis can be performed without explicit system equations, enabling scalable and model-agnostic assessment.

A key strength of the framework is its reliance on data rather than detailed vendor models, making it well suited for IBR-dominated systems where components are often provided only as black-boxes. Leveraging black-box simulators, the methodology enables effective stability evaluation and extends naturally to hybrid co-simulation models, underscoring its versatility and relevance for modern grids. Its efficacy is validated through power system case studies across multiple simulation platforms.

This work demonstrates that a data-driven Koopman framework can transform how operators and planners approach transient stability analysis in IBR-rich grids. By learning stability boundaries directly from simulation data, the method reduces reliance on detailed models and avoids the computational burden of brute-force time-domain studies. Once trained, the Koopman operator provides rapid and scalable estimates of critical clearing times across diverse contingencies, enabling broader and more timely security assessments. The implication for industry is a practical

tool that supports large-scale contingency screening and near real-time decision making as renewable penetration deepens. Looking ahead, the Koopman framework can also be extended to voltage stability, providing a unified data-driven approach to assessing both angle and voltage security in modern power systems.

Project Publications:

- [1] A. R. Matavalam, B. Hou, H. Choi, S. Bose, and U. Vaidya, “Data-driven transient stability analysis using the Koopman operator,” *International Journal of Electrical Power & Energy Systems* 162 (2024): 110307.

Project Publications Under Preparation:

- [1] C. Anirudh, A. R. Matavalam, V. Vittal, B. Hou, and S. Bose, “Koopman Operator-Based Data-Driven Transient Stability Analysis with Hybrid EMT–Phasor Models”

Student Theses:

- [1] Boya Hou (2024), *Nonparametric sparse learning of dynamical systems*. Details available at <https://www.ideals.illinois.edu/items/134403>.