



Integration of Protection and Control Systems in Dynamic Security Assessment Methods

Final Project Report

S-105

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



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Power Systems Engineering Research Center

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The report has two parts. Part I is the ASU contribution. Part II is the Georgia Tech contribution.

Executive Summary

Part I: Arizona State University

The growing integration of inverter-based resources (IBRs) into modern power systems poses new challenges for ensuring transient stability and secure operation, particularly during and after faulted conditions. One of primary objectives of this work is to develop a real-time Artificial Intelligent (AI)-based Dynamic Security Assessment (DSA) framework, which is developed and examined using IEEE 39-bus system during this project. Another objective of this project is to prepare and extend this tool for the Western Electricity Coordinating Council (WECC) system model. Achieving this goal requires access to historical WECC event data, as well as a comprehensive system model to generate accurate datasets for training online AI-based DSA tools. To meet this requirement, the WECC network is modeled in DIgSILENT PowerFactory, chosen for its ability to support root mean square (RMS)- electromagnetic transients (EMT) co-simulation and incorporating manufacturer-validated relay models.

This report describes the process of representing the WECC system in DIgSILENT, including data migration, discrepancy resolution, and the integration of detailed protection systems. In addition, the IEEE 39-bus system is modeled in DIgSILENT and modified to include IBRs. This modified test system is used to generate datasets via RMS–EMT co-simulation for evaluating the performance of AI-based DSA tool.

The generated data are used to train Random Forest (RF) and Convolutional Neural Network (CNN) models to predict distance relay operation during and after fault events, using impedance trajectories obtained from phasor measurement unit (PMU) locations. The results show that the proposed AI-based DSA tool achieves high prediction accuracy with rapid inference capability, enabling timely decision support for system operators. This work establishes a scalable, protection-aware foundation for integrating real-time DSA into operational practices, enhancing reliability in IBR-rich power systems.

Part II: Georgia Institute of Technology

This project is focused on identifying operational security vulnerabilities in T&D assets of an electric power system dominated by IBRs. It focuses on the performance of protection and control systems and the implications of this performance on the dynamic security of the system. Georgia Tech effort for this project has been focused on the following three parts of the study. (1) Proper representation of inverter-based resources in dynamic studies by developing a co-model of the power system, the IBRs, and the protection and control system, (2) Investigation of protection response including normal performance of protection and control as well as failures of protection and control systems, and (3) developing the framework for dynamic security assessment of an IBR dominated electric power system.

This report aims to understand the causes of disturbances and contingencies when Inverter-Based Resources (IBR) are connected or suddenly disconnected from the grid or when a fault occurs in the system and there is interaction between the power system and protection response and the controllers of IBRs. It explores the extent to which follow up responses are expected to occur and examines the implications for existing legacy protection schemes using real-life test cases. The report begins by introducing the problem statement and providing examples of real-life incidents

that occurred in the US and around the world due to IBR triggered disturbances and other transients. The report provides explanations why this work is crucial for determining the optimal design and positioning of new IBR projects to minimize disturbances in the grid.

Chapter 2 of the report is devoted to the development of a co-model of power system, IBRs and protection and control. The integrated co-model consists of (a) a breaker-oriented, physically-based three-phase electric power system model, including IBRs, (b) the P&C system with links to the physical power system, and (c) automated procedures to extract the positive sequence and EMT co-model from (a) and (b). The co-model is symbolically shown in Fig. 2.1 comprising power components, relays, merging units and the interconnection between the power components and the protection devices. The co-model enables co-simulation of the power and P&C systems during any disturbance, i.e. a fault event, etc., to determine the response of the system, i.e., whether the disturbance will be properly cleared and there will be no follow-up events or whether there will be follow-up events, such as a common mode outage, cascading outages and possibly instability. It is important to note that it is possible that the response of the P&C system to cause all of the above-mentioned follow-up events, even if the P&C system would have performed as designed, i.e., no failures within the P&C system. There is a certain probability that failures within the P&C can occur, such as breaker failure, hidden failures in instrumentation and devices as well as P&C changes due to cyber-attacks. We use a probabilistic model of breaker failure, hidden failures and/or cyber-attacks of the P&C system. The probabilistic models enable the co-simulation to capture the consequences of failures in the P&C system.

We also propose the development of an automated procedure to convert part of the power system co-model into a positive sequence (per-phase equivalent) bus-oriented model. This co-model will enable faster simulation of the system when all faults have been cleared and will facilitate efficient application of other analysis methods such as the energy function method and time domain simulation of the un-faulted system. For demonstration purposes we converted the IEEE 24 bus reliability system, which is based on symmetrical component modeling and bus-oriented model, into a **24-substation**, three-phase, physically-based, breaker-oriented, P&C system inclusive model. Each substation is modeled with variable breaker arrangements, for example ring-bus, breaker and a half, double breaker, etc.

Chapter 3 of the report uses the co-model to characterize the response of the system to faults and disturbances and how this response shapes the contingencies that the system will experience. The overall objective of this task is to identify events which may result in major system disturbance by triggering common mode outages, follow-up outages and/or cascading outages. For this purpose, the co-model is utilized to perform co-simulation to answer the following questions: (a) how long of a co-simulation is needed to capture all the effects of a fault event, and (b) can part of co-simulation switch to single phase (positive sequence) co-simulation once faults have been cleared so that the co-simulation can proceed with the much more efficient analysis of positive sequence based models, and (c) can and at what point in the time domain co-simulation one can switch to other direct DSA methods to determine whether the system is stable.

P&C failures have been integrated into the co-simulation using a Monte Carlo type approach. We investigated the feasibility of developing selection of critical P&C failures via sensitivity methods, which are expected to be more efficient. We determined that a time simulation period of four

cycles after the last protective relaying response, i.e. after the fault(s) have been cleared to establish the post fault level of disturbance of the system, is enough to take the system to a point where the simulation can continue with a simplified model. The post fault(s) conditions of the system are used to assess dynamic security with more efficient methods. We introduced the Energy Method to assess the stability of the system.

Chapter 4 provides a framework for performing dynamic security assessment in an IBR dominated power system, using the co-model. The objective of this task is to determine the long-term dynamics after the fault(s) have been cleared and whether the post fault dynamics will result in more relay actions such as tripping of an unstable generator. First, dynamic security assessment is conducted in RMS-EMT co-simulation. Second, we use energy function methods for faster DSA as follows: continue the time domain co-simulation of the co-model for four cycles after the last fault has been cleared. At that time, we switch to an energy function method using the approach described in [9]. Specifically, the manifold of the center of oscillations is computed from the time domain co-simulation data using estimation methods. The center of oscillations manifold is identified as points in the system for which the frequency varies linearly with time (does not oscillate). Knowledge of the center of oscillations enables the computation of the total energy of each generator, i.e. kinetic and potential energy, as well as the potential barrier of each generator. The kinetic energy of each generator is directly computed. The potential energy requires the manifold of the center of oscillation and the present state of the generator. Note that the manifold of the center of oscillations may be slowly moving with time. Once the total energy is computed, a direct comparison to the total energy of a generator to the potential energy barrier will determine the stability or instability of the specific generator.

Chapter 5 presents a summary of the work and how the work at Georgia Tech is integrated with the work at ASU. It also provides an assessment of how this work contributes to the needs for assessing the dynamic security of an IBR dominated power system, considering the response of protection and control systems. While this project made important developments for dynamic security assessment of IBR dominated power systems integrated with protection and control systems, the topic is very broad and complex and more research will be needed to bring these developments to practical use.

The report also includes two Appendices. Appendix A presents the co-model of the IEEE 24 Substation RTS. Specifically, the co-model is based on the IEEE 24-bus Reliability Test System which has been converted into a 24-substation test system with integrated protection and control (co-model) and the ability to easily change synchronous generators into IBRs. Appendix B presents multiple events conducted on the IEEE 24 Substation RTS and the response of the protection and control to these events.

Project Publications:

- [1] Reza Cheshomi, Amir Esmaili-Nezhad and Mojdeh Khorsand, "Online Machine Learning-Based Dynamic Security Assessment With Protection Modeling Trained on RMS-EMT Co-Simulation Data," *North American Power Symposium 2025*.

Student Theses:

- [1] Reza Cheshomi, *Hybrid RMS-EMT Co-Simulation and Machine Learning-Based Dynamic Security Assessment for Inverter-Based-Resource-Dominant Power Systems*, PhD Dissertation, Expected May 2027.