



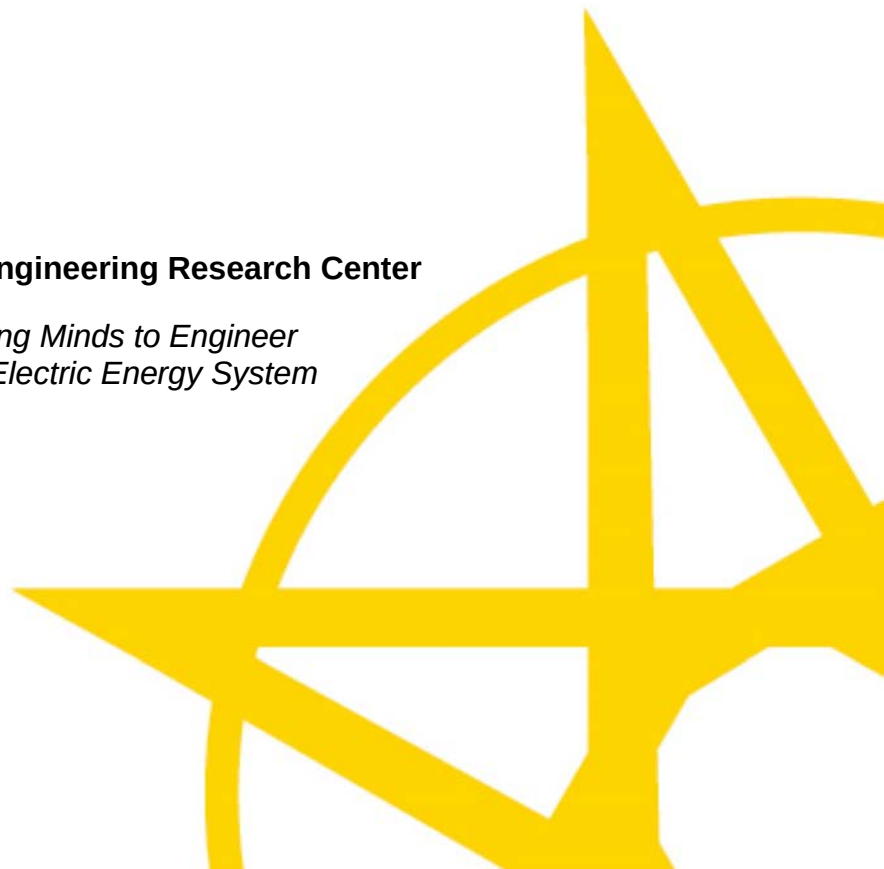
Representation, Modeling, Data Development and Maintenance of Appropriate Protective Relaying Functions in Large Scale Transient Stability Simulations

Final Project Report

S-66

Power Systems Engineering Research Center

*Empowering Minds to Engineer
the Future Electric Energy System*



Representation, Modeling, Data Development and Maintenance of Appropriate Protective Relaying Functions in Large Scale Transient Stability Simulations

Final Project Report

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Executive Summary

After a major disturbance, the power system response is highly dependent on protection schemes and system dynamics. Improving power systems situational awareness requires accurate and simultaneous modeling of both protection schemes and dynamic characteristics in power systems analysis tools. Historical information and ex-post analysis of blackouts reaffirm the critical role of protective devices in cascading events, thereby reinforcing the necessity to represent protective schemes in transient stability studies. The primary goal of this report is to investigate and examine the importance of modeling protection systems during transient stability studies and to develop systematic techniques to identify and represent critical protective relays in large commercial transient stability software packages. In addition, this report proposes a method to identify the appropriate locations of out-of-step blocking schemes in order to prevent relay mis-operations during unstable power swings. The report is presented in two parts.

Part I: Analytical Approaches for Identification and Representation of Critical Protection Systems in Transient Stability Studies

Part I of the final report on PSERC project S-66 studies the importance of representing protective relays in power system dynamic studies. The results have clearly confirmed the critical nature of accurate protection system modeling within stability studies.

Moreover, Part I of this report proposes a novel method, the minimum voltage evaluation method, to determine the location of the mis-operating relays at the planning phase. Blocking these mis-operating relays, combined with an appropriate islanding scheme, helps avoid a system-wide collapse. The proposed method is tested on data from the Western Electricity Coordinating Council (WECC). A triple line outage of the California-Oregon Intertie (COI) is studied. The electrical center is determined and appropriate out-of-step blocking schemes are identified. The results of this test show that:

- The correct design of out-of-step protective relays and representing these relays in transient stability studies improve the dynamic performance of the power system and reduces the fluctuations in voltage and frequency throughout the system.
- The minimum voltage evaluation method is able to detect the potential mis-operating relays accurately.
- The minimum voltage evaluation method augments and enhances the remedial action scheme (RAS) associated with the California-Oregon Intertie outages. The out-of-step (OOS) blocking scheme based on the proposed method, along with the Northeast/Southeast (NE/SE) separation scheme, provides a proper controlled islanding scheme.
- Assessing the voltage drop is a reliable evaluation method to detect the electrical center of the system. Blocking only the relays, which experience their relay impedance trajectories intersecting their line impedances, is an insufficient strategy and may result in uncontrolled islanding.
- OOS relays have to be designed with great care. Failure to detect all mis-operating relays may result in failure of the islanding scheme and may lead to a system-wide collapse.

Furthermore, Part I of this report presents a systematic method to determine essential relays to be modeled in transient stability studies. Although modeling all of the protective relays within transient stability studies may result in a better estimation of system behavior, representing, updating, and maintaining the protection system data becomes an insurmountable task. Inappropriate or outdated representation of the relays may result in incorrect assessment of the system behavior. The desired approach should identify protective relays that are critical for various operating conditions and contingencies. The proposed strategy is verified as a viable technique based on results obtained from the WECC 179-bus and the IEEE 145-bus test cases while considering various operating states and contingencies. This report shows that:

- The proposed strategy is able to identify all mis-operating relays for various operating conditions and contingencies.
- Modeling only the identified critical protective relays is sufficient to capture system behavior and precludes the need to model all protective relays.

In summary, Part I of this report contributes to the challenges of this topic by studying and clarifying the importance of protective relays modeling in transient stability studies, by presenting a strategy to detect mis-operating relays during unstable power swings, and by proposing a strategy to identify critical protective relays.

Part II: Evaluation of Relay Dynamic Response by Utilizing Co-simulation Platform (PSS/E-CAPE) and a Loss of Excitation Detection Algorithm to Prevent LOE Relay Mis-operation during Power Swing Cycle.

The objective of the work at Washington State University is to assess the transient response of protection system. Based on the literature, most of the catastrophic blackouts in the United States were triggered by unwanted operations of protective relays. Calibrating and testing the relays based on the steady state condition cannot provide the realistic and appropriate vision of the protection system performance during the transient condition. In this project a co-simulation platform is utilized to evaluate the dynamic response of the protective relays. CAPE-Transient Stability (CAPE-TS) module provides an internal interface between CAPE software and PSS/E software.

Transient performance of distance relays and loss of excitation relays as the most utilized protection devices in the power grid are analyzed in the co-simulation platform. Conventional schemes of distance relays and loss of excitation relays are modeled and the mis-operation conditions are investigated. Moreover, the Western Electricity Coordinating Council (WECC) with more than 20000 buses and 3000 generators is modeled in the co-simulation platform. Distance relays are modeled based on the typical settings and their responses are studied during the triple line outage (TLO) of California-Oregon Intertie (COI). It is shown that appropriate modeling and settings of the distance relays equipped with blocking function can enhance the dependability and security of the protection system and prevent catastrophic cascading outages and stop initiating urgent operation of predetermined remedial action schemes (RAS) in the large scale power system.

Besides, some protection schemes were studied to discriminate faulted condition and power swing condition for distance and LOE relays. The wavelet transform method based on the signal

processing technique is studied. In this strategy, the voltage and current signals of the relay terminal are decomposed in to various detail coefficients and it is shown the power swing condition can be detected based on the remarkable difference between the magnitudes of these coefficients.

Furthermore, secure and reliable operation of the synchronous generator as one of the important component in the power system is vital for the entire power system. So the correct operation of LOE relays as the main machine protection relay is important. Thus, in the last section of part II of this report, a novel approach in detecting loss of field condition is proposed. In this technique, the rate of change of the generator angle is calculated in each sampling window. Based on the polarity of this variable and the slip frequency magnitude, LOE contingency is distinguished from power swing. The validation is obtained through different simulation test cases on single machine infinite bus system. The simulation results show that adding the proposed algorithm to the conventional LOE relay prevents mis-operation of the relay and unwanted tripping of the generators.

In summary, Part II of this report studies the transient relay testing in the more realistic environment by utilizing CAPE-PSS/E co-simulation platform. It is shown that transient evaluation of relay performance can provide better vision for system operators of large scale power networks such as WECC system. Then, new free-setting LOE detection scheme is presented and tested to identify LOE condition.

Project Publications:

- [1] M. Abdi-Khorsand and V. Vittal, "Modeling Protection Systems in Time-Domain Simulations: A New Method to Detect Mis-operating Relays for Unstable Power Swings," *IEEE Transactions on Power Systems*, vol. 32, no. 4, pp. 2790-2798, Jul. 2017.
- [2] M. Abdi-Khorsand and V. Vittal, "Identification of Critical Protection Functions for Time-Domain Simulations," *IEEE Transactions on Power Systems*, submitted Mar. 23, 2017.
- [3] I. Kiaei, S.Lotfifard, A. Bose, "Evaluation of Protective Relay Dynamic Response Via a Co-simulation Platform," to be submitted to *IEEE Transactions on Power Delivery*.

Student Theses:

- [1] Mojdeh Khorsand Hedman. *Analytical Approaches for Identification and Representation of Critical Protection Systems in Transient Stability Studies*. PhD Dissertation, Arizona State University, Tempe AZ, May 2017.