



Comparison of Positive-Sequence Simulation Versus Three-Phase Simulation of IBRs and Rotating Loads in Time Domain Simulations

Final Project Report

S-101G

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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Executive Summary

With the significant penetration of IBRs at both the transmission and distribution level and the inability of conventional phasor domain tools to accurately represent the dynamics of single phase components, there is an urgent need to examine the use of tools that allow the flexibility to model systems in three-phase detail and conduct time domain simulation. Positive-sequence time domain tools, primarily, either assume that the composition of these single-phase devices is balanced across the three-phases allowing for a dynamic representation in positive-sequence simulation tools, or develop performance based models to represent these devices in time domain simulations. Additionally, inverter-based resources (IBRs) are very fast acting devices and can comprehensively alter the dynamic phenomena in power systems. The need to represent these devices in greater detail using an electromagnetic transient (EMT) representation and conduct a co-simulation in which the rest of the system in phasor domain detail in order to contain the computational complexity is critical. The research topic being addressed in the S-101G project has been identified as a critical need by several PSERC member companies. Thus, the primary objective of this project is to compare the positive sequence and EMT analysis with high penetration of inverter-based resources electric grids.

This project examines the simulation of both distribution connected and bulk system connected IBRs in a three-phase (phasor as well as EMT) setting and comparing the results of the simulation versus the traditional positive-sequence time domain simulation using the software package DIgSILENT PowerFactory. The project also examines the efficacy of modeling IBRs and the rest of the system in in EMT detail. The performance of the system in EMT detail is compared against representing the entire system in positive sequence detail. This work characterizes the advantages of these detailed representation and compares the performance of this detailed representation with the conventional positive-sequence simulation and determines the advantages provided by the more detailed representation. The results also characterize the differences between the two modes of simulations and identifies instances in which they differ. Further, this project analyzes the applications of EMT analysis, scenarios where EMT detail is required to observe a phenomena or transients for better understanding of the same.

The following tasks have been accomplished to achieve the above-mentioned findings. Initially, an integrated transmission-distribution (T&D) network has been developed both in EMT and positive sequence detail. In this work, the WECC 3-machine 9-bus system is used to model the transmission system. The loads in the original system at one bus are modeled using a detailed distribution system representation developed in this project and use electromagnetic transient (EMT) models for three-phase induction motors, single-phase induction motors, and single-phase distributed energy resources (DERs). An actual feeder in Arizona is used to develop the distribution feeder model. The detailed feeder model is reduced to a three-phase three-segment equivalent and the loads and DERs along the feeder are dynamically equivalenced using a novel procedure developed in this project. The novel procedure developed has been validated against the detailed feeder model. As an example of applying this novel equivalencing procedure, details of the model development and simulation results for selected North American Electric Reliability Corporation (NERC)-recorded disturbances are presented in the report. Once the integrated T&D network has been developed, several validations and tests have been carried out against the NERC-recorded disturbances. While validating the network, a 120 Hz oscillation in transmission level

voltage and power quantities is observed. Such oscillations are due to the effect of the unbalanced distribution network which cannot be usually observed in positive-sequence studies. Thus, the interaction of distribution networks with the transmission system has been clearly examined.

With detailed EMT modeling, the development of positive sequence models and appropriate benchmarking of the same has been discussed. The benchmarking procedure is validated by comparing the positive sequence model's response against those of the EMT models developed. The integrated T&D network has been tested for voltage and frequency disturbances. In the case of balanced faults, it is observed that the EMT response closely matches the positive sequence analysis response. However, for unbalanced fault cases, a difference in response is observed which is due to the difference in distribution system representation and in detailed single-phase component modeling. In general, the positive sequence and EMT analysis results in similar response for the symmetrical disturbances. For unsymmetrical disturbances among the phases, the results are significantly different largely because of the representation of the loads in the distribution system and stalling and tripping of motor loads in separate phases which is not captured accurately by the positive sequence analysis.

With transmission level IBRs (solar and wind plants), induction motor drives and plugin electric vehicle (EV) topology developed, the analysis has been carried out for balanced and unbalanced fault conditions. Some of the findings are listed as follows. If the feeders are identical, the EMT and positive sequence analysis yield closely match results for balanced fault conditions. However, the results are different for unsymmetrical faults largely because of the impact of the faults on load components, especially single-phase motor loads and DERs that trip in the phases most impacted by the unsymmetrical faults. Besides, the impact of dc dynamics on the transmission level IBRs yielded different active power responses of the IBRs between EMT and positive sequence analyses.

This report identifies the following factors that primarily contribute to the differences between EMT and positive sequence analysis. They are,

- Non-identical DER, and motor representation and associated difference in the motor parameters
- Unbalanced fault characteristics leading to different impacts on individual phases not captured by positive-sequence analysis,
- Capturing the interaction of IBRs and DERs on motor stalling behavior,
- Detailed dc side modeling of IBRs
- Fault location and characteristics, and
- Feeder Representation.

Project Publications:

- [1] G. V. Iswaran, V. Vittal, M. Khorsand, D. Ramasubramanian, P. Mitra, "Comparison of Positive Sequence and Three-Phase Time Domain Simulations with IBRs and Rotating Loads", IEEE Transactions on Power System, *yet to be submitted*.

Student Theses:

- [1] Giritharan Vijay Iswaran. “Analyzing the Capability of Positive Sequence Simulations and Three-Phase Simulation Requirements for Power Electronic Dominated Grids”, Dec. 2025.