



Guidelines for Voltage Stability Assessment on Systems with Large Integration of IBRs

Final Project Report

S-108G

Power Systems Engineering Research Center
*Empowering Minds to Engineer
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PSERC Publication 24-08

December 2024

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Acknowledgments

We would like to express our gratitude to the project advisors for their technical feedback and insightful suggestions, particularly:

- Alberto Del Rosso, EPRI
- Mahendra Patel, EPRI
- Tamer Ibrahim, EPRI

Executive Summary

Large integration of renewable variable generation and inverter-based resources (IBR) alters the system's response to contingencies and fault events, and consequently the ability of the system to preserve stable operation under critical conditions. Renewables and IBRs affect voltage stability in various ways, and consequently There is an urgent need to reevaluate stability assessment methods for Transmission and Distribution (T&D) systems with high penetration IBRs.

The inherent uncertainty associated with IBRs significantly impacts both short- and long-term voltage stability. A critical challenge in this context is the accurate modeling of IBRs for stability assessments, as it requires a comprehensive understanding of their interactions with system dynamics. Additionally, the volt-var control (VVC) produces the reactive power and enables IBRs to participate in voltage regulation within distribution systems. Therefore, replicating the reactive support capabilities of IBRs in stability studies is crucial, as it can significantly enhance the reliability of both transmission and distribution networks.

The work evaluated the stability of T&D systems under significant integration of IBRs. Two approaches were employed for the stability assessment: a T&D co-simulation framework and an aggregated model representation. The co-simulation approach utilized detailed modeling of the distribution network, capturing the effects of imbalances, resulting in a reduced voltage stability margin (benchmark for comparison). In contrast, the aggregated models provided a conservative and optimistic stability margin by overlooking the intricate details of the distribution networks. In addition to this, we developed an aggregated model to incorporate the VVC into stability, which yielded an optimistic estimate of the stability margin. Notably, the inclusion of VVC in the aggregated models resulted in a good voltage match with the T&D co-simulation studies.

Major outcome of the analysis is that the aggregated model used for voltage stability assessment effectively estimates the stability margin of IBR-rich grids. Regardless of varying load models in the distribution network, the aggregated model consistently produces conservative or optimistic results, remaining close to the true margin. Moreover, if transmission operators set the voltage threshold to 0.9 p.u. for stability assessment, incorporating VVC in the aggregated models achieves comparable accuracy to the T&D co-simulation.

Project Publications (All the Manuscripts are under preparation):

- [1] Anirudh C.V.S and Amarsagar Reddy Ramapuram Matavalam "Evaluating the Impact of IBR Volt-VAR Control on Voltage Stability through QV Analysis," *IEEE Transactions on Power Systems*.
- [2] Anirudh C.V.S and Amarsagar Reddy Ramapuram Matavalam "Impact of Distribution System Strength on Voltage Stability Assessment in IBR-Rich Grids," *IEEE Transactions on Power Systems*.
- [3] Anirudh C.V.S and Amarsagar Reddy Ramapuram Matavalam "Enhanced Aggregated Models for Voltage Stability Assessment through PV Analysis," *IEEE Transactions on Power Systems*.