A Probabilistic Approach to Voltage Security Assessment with High Penetration of Renewable Generation

Maiara Oliveira[1], Rodrigo Ramos[2], Luis Fernando Alberto[2], Ahda Pavani[3]

[1]National Electric System Operator, [2]University of Sao Paulo, [3]Federal University of ABC

The energy transition presents new challenges for power system planning and operation, particularly due to the increasing penetration of intermittent renewable sources. Ensuring a reliable balance between generation and demand requires advanced methodologies that account for variability and uncertainty. This study introduces a novel probabilistic framework for analyzing the Voltage Security Margin (VSM), incorporating spatial and temporal correlations between renewable sources while considering seasonal and hourly variations in operational scenarios. A key feature of the proposed methodology is the identification of rare events that may trigger voltage instability, addressed through an importance sampling optimization based on the Cross-Entropy (CE) method. To validate its accuracy and computational efficiency, the CE-based approach was compared against conventional Monte Carlo (MC) simulations, demonstrating equivalent results with significantly lower computational effort. Moreover, the methodology was applied to the entire large-scale Brazilian power system, further confirming its practical applicability and robustness. The results highlight the importance of integrating probabilistic criteria into stability assessments, enabling a more comprehensive and reliable evaluation of voltage security under uncertainty. By enhancing renewable generation characterization and risk assessment, the proposed approach supports more secure and flexible power system operation amid increasing variability.

979-8-3315-8138-1