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Applications Of Contingency Analysis To Improve Robustness And Resiliency Of Power Systems

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The transformation of transmission power systems in recent years has been profound, primarily driven by the global energy transition and the increasing integration of renewable energy sources (RESs). As societies strive to reduce their carbon footprint and mitigate the effects of climate change, there has been a paradigm shift towards cleaner and more sustainable energy generation methods. This shift has necessitated significant changes in the way electricity is generated, transmitted, and distributed. In the landscape of modern power systems, the satisfaction of continuous and uninterrupted electricity supply is of paramount importance, particularly amidst the integration of RESs. This study delves into the applications of contingency analysis to enhance the robustness and resiliency of transmission power systems. Here robustness is defined as a degree to which a power system is able to withstand an unexpected event without degradation in performance, and resiliency is defined as its ability to adapt to changing conditions and keep supplying critical loads even during and after extreme contingencies.

To enhance the system's robustness and resiliency, additional renewable generation units can be strategically placed within the power system, and control remedial actions can be implemented to support post-contingency recovery processes (Stankovic et. al., 2023). The remedial actions may be executed automatically by a control system or manually by a system operator to mitigate the effects of a disruption or strengthen the system to withstand a possible future contingency. System adjustments may include the opening or closing of a transmission element; the opening, closing, or redispatch of a generator; or the curtailment of load etc. (Diahovchenko et al., 2021). These system adjustments may include actions that occur every time a certain contingency occurs or actions that occur only when certain system conditions are met.

The identification of suitable buses for RESs allocation involves considering the power system as a graph (Bharti, 2020; Diahovchenko et al., 2021). Five centrality-focused graph metrics were selected to aid in pinpointing optimal bus locations for RES allocation. Pairwise comparison of these metrics, following the Saaty scale, allows for the calculation of a complex robustness score for each bus utilizing the Analytic Hierarchy Process (AHP). It is considered that inconsistency of up to 10% can be tolerated for AHP (Diahovchenko et al., 2023).

The power system's graph can be represented as an adjacency matrix, or an admittance matrix, or a "reliability matrix." The reliability matrix, in particular, accounts for the reliability scores of the edges between the graph's nodes. While a classical adjacency matrix is unweighted, an admittance matrix weights the connections between the nodes through the branches' admittances, and the reliability matrix has reliability coefficients assigned to each branch. It should be noted that the reliability coefficients depend on the type of the branch, on the redundancy, and the operational conditions (i.e., normal operation or contingency mode). They can change, depending on the performance of the transmission branches during contingency scenarios, and should be updated accordingly.

This study examines the normal operation (base case) and the N-1, N-2, and N-3 contingencies of a modified IEEE 14-bus system, a modified 14-bus system with reinforcements (i.e., with additional transmission connections), and of the IEEE 37-bus system. For each of the considered models, the base case implies that the power system is in its normal steady-state, operation, with all elements in service that are expected to be in service. For contingency scenarios, which can be both planned or unplanned, a loss of one or more system elements occurs (Jianzhong G. et.

al., 2021).

The results of the base cases modeling and the contingency tests are used to formulate the reliability matrices for the power system under study, considering its performance and the state of the branches (e.g., tripping, overloading), under normal operating conditions and under unplanned disruptions (i.e., under the N-1, N-2, and N-3 contingencies). Simulations of the power systems' operation are conducted using the PowerWorld 23 software, with centrality metrics, robustness scores, and resiliency indicators obtained through Python code. The resiliency performance is then proportional to the amount of critical loads served/unserved, considering the system's adaption and the remedial action schemes.

Differences in priority ranking of the modified IEEE 14-bus system are shown in Figure 1 as an example. The priority for generation units' allocation depends on a way of the graph's matrix representation (i.e., with an adjacency matrix, with an admittance matrix (denoted as weighted), with reliability matrices for N-1, N-2, and N-3 scenarios). In this example, the first RES should be placed at Bus 4, and all the ranking methods are in agreement about this location. However, if there are more generation units are to be added, the allocation priorities can vary depending on the method. For instance, a second renewable generation unit is to be placed at Bus 5 or Bus 9; a third generation unit – at Bus 5, or Bus 6, or Bus 9, etc.

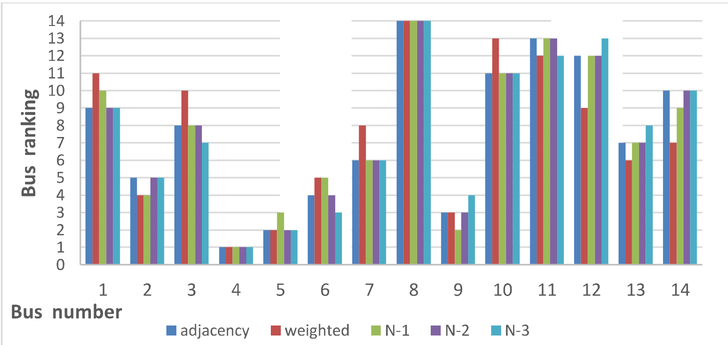

Fig. 1. Differences in priority ranking of the 14 bus system.

The findings show that reliability matrices assist in optimizing the allocation of additional RESs to enhance system robustness and resiliency by integrating reliability states of transmission lines and transformers across contingency scenarios, offering a more targeted approach compared to conventional graph representations like adjacency and admittance matrices. These results validate the efficacy of utilizing reliability matrices, which can be different for various contingency scenarios, in advancing power system analysis and development planning.

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References

Bharti, D., Mala, D. 2020. A Centrality Index Based Approach for Selection of Optimal Location of Static Reactive Power Compensator. Taylor & Francis Group.

Critical infrastructure security and resilience 12. Presidential Policy Directive/PPD–21. 2013. US: White House. https://obamawhitehouse.archives.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil.

Diahovchenko, I. et. al. 2021. Resiliency-driven strategies for power distribution system development. Electric Power Systems Research. 107327.

Diahovchenko, I.M, Kandaperumal, G., Srivastava, A.K. 2023. Enabling resiliency using microgrids with dynamic boundaries. Electric Power Systems Research. 109460.

Jianzhong, G. et. al. 2021. Transmission Adaptive Capacity-Based Resilience Metrics for Power Grid Contingency Analysis. 2021 North American Power Symposium (NAPS). IEEE.

Stankovic, et. al. 2023. Methods for Analysis and Quantification of Power System Resilience. IEEE Transactions on Power Systems. 4774-4787.