Efficient Topology Assessment for Integrated Transmission and Distribution Network with 10,000+ Inverter-Based Resources

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Background/Objectives. The renewable energy proliferation calls upon grid operators and planners to systematically evaluate the potential impacts of distributed energy resources (DERs). Considering the significant differences between various inverter-based resources (IBRs), especially the different capabilities between grid-forming inverters and grid-following inverters, it is crucial to develop an efficient and effective assessment procedure besides available co-simulation framework with high computation burdens.

Approach/Activities. This paper presents a streamlined graph-based topology assessment for the integrated power system transmission and distribution networks. The simulated system consists of one transmission network (T) and multiple replicas of the testing distribution network (D). The T network is a modified miniWECC model including 41 synchronous generators and 21 load buses. Each D network consists of one test feeder model that is connected to the T network through the load or interconnection buses. For our simulation, the IEEE 8500-node test feeder is used. Graph analyses were performed on the integrated graph. A high-performance computing cluster with 40 nodes and total 2400 CPUs has been utilized to process this integrated graph, which has 100,000+ nodes and 10,000+ IBRs. Two case studies are conducted to demonstrate the effectiveness of the proposed topology assessment method. In Case 1, we assess the resilience of the topology under normal operation, when energy flows from generators in the T network to loads in the D network. We identify the most important nodes in both networks using the cross-closeness centrality and the cross-betweenness metrics. In Case 2, we investigate the resilience of the system in a black start restoration scenario. We compare the distribution of node importance in the system under different circumstances: a) solely relying on traditional synchronous generator based black start and b) with the help of grid-forming inverters. Comparing these two distributions, the distribution for b) is much flatter, i.e., has much fewer high-importance buses and more low-importance buses. This suggests that by involving GFM IBRs, there are fewer critical buses in the network for black start restoration, which makes the system more resilient.

Results/Lessons Learned. Graph analyses were performed based on the integrated graph of modified miniWECC grid model and IEEE 8500-node test feeder model, which has more than 10,000 inverter-based distributed generation resources. The node ranking results not only verified the applicability of the proposed method, but also revealed the potential of distributed grid forming (GFM) and grid following (GFL) inverters interacting with the centralized power plants.