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Grid forming inverters for system restoration

This presentation discusses the contribution of various possible black start capable generators in power systems with a high share of inverter-based resources. Options investigated include a grid-forming battery energy storage systems (BESS), a thermal synchronous generator, and a combination of a grid-following BESS and a nearby transmission connected synchronous condenser. The response of each option is assessed with the use of detailed vendor-specific electromagnetic transient (EMT) simulation models. These studies investigate the response of each candidate black start option in energising network transformers and transmission lines, as well as their ability in restarting large induction motor-based loads and grid-following inverters. Vendor-specific models of different types of grid-following inverters including wind and solar farms, and grid-following BESS are analysed (note that this grid-following BESS differs from that mentioned as a potential black-starter in conjunction with a synchronous condenser). Distance and differential relays were also included in the overall simulation model to assess the potential mal-operation of these relays under low fault level conditions during early stages of system restoration when subject to a network fault.

Studies conducted simulate the step-by-step energisation process for each candidate black start option. The impact of various contingencies that might occur in the early stages of system restoration, e.g., fault occurrences, generation reduction, load tripping were then studied for each step. These studies demonstrate that all three options can provide viable black start contribution.

Despite providing a lower fault current contribution to that of a synchronous generator, the grid-forming BESS was identified as the most capable black start option. This stems from its faster response to voltage and in particular to frequency disturbances, and the inherent ability to act as a generator or as a load. The latter is important as it will provide the flexibility to energise additional grid-following inverters which could otherwise be limited due to the load scarcity especially in network parts with a high penetration of distributed photovoltaic before the blackout. From the three options investigated, the combined grid-following BESS and synchronous condenser was shown to be the least capable in terms of energising other network assets and grid-following inverters. This primarily stems from the fact that neither the gird-following BESS nor the synchronous condenser in isolation can restart the power system, and collectively provide the required voltage and frequency control. Additionally, the required system strength or the short circuit ratio (SCR) for the stable operation of the grid-following inverters need to be provided by the synchronous condenser first. Overall, whilst less capable than the other two options, this is still a viable option due to its technology maturity relative to large grid-forming inverters and utilises existing network and generation.

The studies conducted demonstrate the insignificant impact of inherent parameters of the black-start synchronous generator such as fault current, inertia and damping. The grid-forming BESS used emulate the latter two aspects of the response with its control systems, however, the variation of these parameters did not noticeably alter the response and the overall black start capability in the power island studied.

The key area where the grid-forming BESS outperforms the other two options is the ratio of MVA capacity of the black starter compared to the MVA capacity of grid-following inverters it can energise. This ratio was also determined to be dependent on the SCR withstand capability of the grid-following inverters whereby the lower the SCR threshold which can be withstood by them whilst connected to the grid, the higher it will be the ratio of the installed MVA of the black-start option to the energised MVA of grid-following inverters.