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Black-Start Restoration Assisted by Mobile Energy Storage Systems

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Introduction

- Overall goal: prepare and restore the power system from full blackout (black-start restoration) while utilizing energy storage.
- Black-start model considerations:
  - Only some generators have black-start (BS) capability.
  - Utilize bulk transmission-level Energy Storage Systems (ESSs), some of which are Mobile ESSs (MESSs)
- First-stage actions for which to prescribe optimal plans:
  - Pre-emptively place MESSs at buses to assist black-start of a generator, generators must have MESS BS capability
- Second-stage actions:
  - Routing of MESSs and operation of all ESSs to support black-start (e.g., voltage support, cranking power).
  - Creation of cranking paths from black-start generators.
  - Typical aspects of power system operation (e.g., generation dispatch, power flow).

Staging MESSs

- The first-stage actions *stage* (or preposition) MESSs at buses before a blackout event.
- MESSs should be staged such that they can quickly travel to important locations in the grid through a transportation network.
- Multiple scenarios should be considered with different disabled components.
- Stationary ESSs are not staged in the first-stage actions.
- Staging decisions are made by solving two-stage optimization.

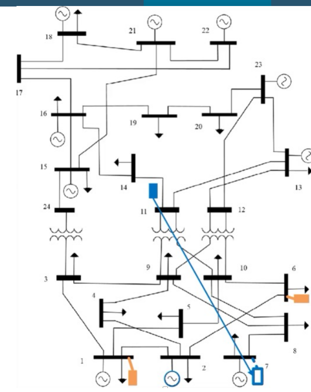

Figure 1: One-line diagram for the IEEE 24-Bus case with 1 MESS (blue) and 2 stationary ESSs (orange).

Routing MESSs

- The model expands on work in [2].
- MESSs are routed during the black-start restoration process.
- Routing occurs through a transportation network represented by a time-space network for each MESS.
- Transportation network is overlaid on top of electric grid and is not illustrated in the figures.
- Routing of an MESS starts from its staged position.
- MESSs may be routed multiple times during the restoration process.
- ESSs may provide cranking power or voltage support.

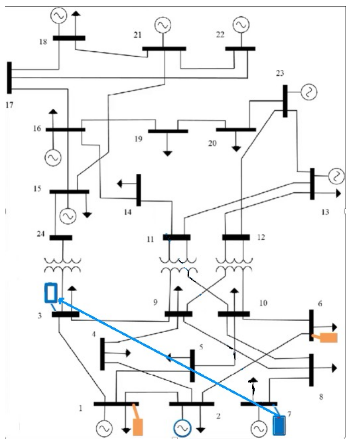

Figure 2: The MESS may travel to other buses through a transportation network during restoration.

Black-Start Model

- The model also expands on work in [1].
- Only BS generators and ESSs can start-up without access to external power.
- During each time interval, all non-energized components adjacent to energized components may become energized.
- After gaining access to external power, non-BS generators may start-up subject to start-up time constraints.
- Line switching allows for different sections of the grid to be restored individually.

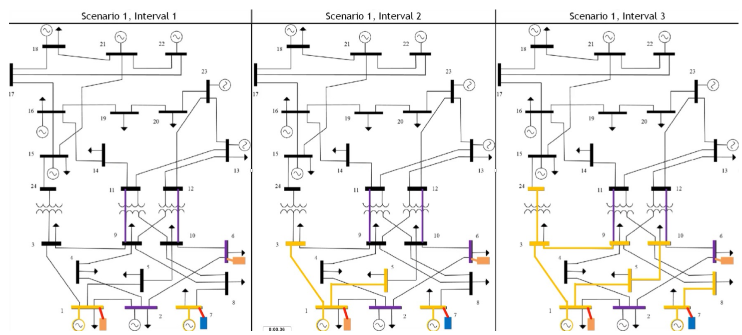

Figure 3: Illustration of energized components spreading throughout the network during consecutive time intervals. Yellow components are energized. Energized components spread throughout the grid similar to a breadth-first search algorithm. Components adjacent to energized components become energized in each time interval.

Initial Results

- Generators on bus 2 have black-start capability.
- Three scenarios consist of different outed components
- Without ESSs we simulate the BS response for each scenario. (Optimization converges to a 23% MIP Gap)
- With ESSs we solve two stage optimization, which stages the MESS on bus 7. (Optimization converges to 55% MIP Gap)
- The inclusion of ESSs reduces the amount of load shed and allows the system to recover faster for each scenario.

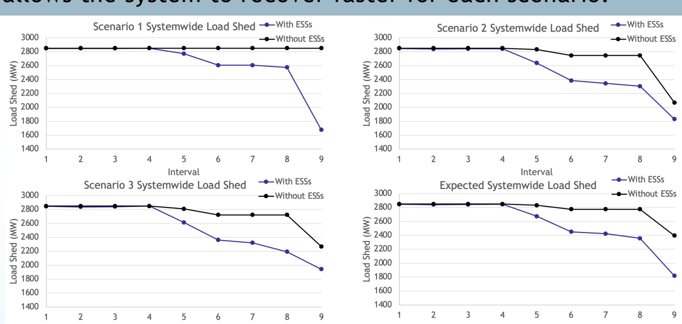

Figure 4: Load shed for each time interval during the recovery process with and without ESSs. All three scenarios and the expected value are plotted.

Conclusions and Future Work

- ESSs can improve the black-start restoration process by reducing total load shed and allowing the system to recover faster.
- Combining the BS restoration optimization problem with the optimal routing problem results in a difficult problem to solve. Future work should focus on solving these problems to an acceptable MIP gap.
- Future work will evaluate the benefits of stationary ESSs versus mobile ESSs during BS restoration.

References

[1] G. Patsakis *et al.*, "Optimal Black Start Allocation for Power System Restoration," *IEEE Transactions on Power Systems*, vol. 33, no. 6, Nov. 2018.
[2] S. Yao *et al.*, "Rolling Optimization of Mobile Energy Storage Fleets for Resilient Service Restoration," *IEEE Transactions on Smart Grid*, vol. 11, no. 2, Mar. 2020.

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