Coordinating Black Start Operations Using Synchrophasors

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Goals

- To use the quickly updated voltage magnitude and phase angle data provided by synchrophasor measurement units (PMUs) to assist efforts to re-energize and reconnect regions of the grid.
- To determine and demonstrate the effectiveness of the algorithm in a laboratory setting.
- To implement the algorithm as part of the black start strategy of utilities.

Fundamental Questions/Challenges

- As PMUs become more commonplace, they promise to provide an unprecedented wide-area view of grid health.
- This view should give operators the ability to identify with more certainty the best opportunity to reconnect two disconnected regions.
- Through repeated application of the algorithm to close across disconnected regions, a system may be restored from a black start.
- In order to close across regions, it is necessary to bring them closer together electrically.
- By monitoring phase angles and actuating controls to bring phase angles on the two sides of an open tie closer, an operator can take more active control of the dynamics within the two regions to make it easier to reconnect them.
- That requires formulation of a schedule of phase angle targets in the two regions.
- Once the schedule is established, controls can be activated on both sides to achieve that schedule.
- With the controls implemented, the steady-state operating points of the two sides should be closer, which should make it easier to reconnect them.

Research Plan

- Considering steady-state characteristics of power systems, develop a way to calculate a schedule for phase angles at the nodes within two disconnected regions to make it easier to close the tie between them.
- Given that schedule, implement controls on the two sides, such as load shedding and generator outputs, to change phase angles to match the schedule.
- Monitor the dynamics of the system to determine if the tie between the two regions may be closed.
- Given the results of simulations, implement the strategy in a laboratory setting. Specifically, take two separated systems in the electric machines lab, perform the calculations just described, and gauge the effectiveness of the approach in helping reconnect the systems.

Research Results

- The algorithm has been written and tested on small systems to determine the target schedule of phase angles. Here is the algorithm:

Sensitivities to injections at each end of the tie to be closed:

$$\begin{bmatrix}\Delta\boldsymbol{\theta}\\ \Delta\mathbf{V}\end{bmatrix} = -[\mathbf{J}(\mathbf{x})]^{-1}[0 \ \ldots \ 0\ 1\ 0 \ \ldots \ 0\ -1\ 0 \ \ldots \ 0]^{\mathrm{T}}$$

To close line tie L_{jk} between the two systems, determine $\Delta\theta_{jk}$ needed to comply with breaker setting on the phase angle difference. Set this value equal to the estimate of the post-close flow on the tie line needed to realize that angle difference.

$$\Delta\theta_{jk} \approx P_{L_{jk}}\left(\Delta\theta_j - \Delta\theta_k\right)$$

Solve for $P_{L_{jk}}$. Multiply this value by the sensitivities $\Delta\theta_i$ and ΔV_i by $P_{L_{jk}}$ to update the angles and voltages at all nodes on both sides of the tie. This establishes the schedule for voltage magnitudes and phase angles on each side of the tie.

Broader Impact

- In the event of a major system event, restoring the system as quickly and safely as possible presents a tremendous but necessary challenge.
- If successful, this tool will help operators meet that challenge.
- It also can be used with microgrids to determine how best to connect them with the broader system.

Interaction with Other Projects

- The local control techniques required in each region to be reconnected will borrow from work on agent-based local control techniques.

Future Efforts

- This project is purely conceptual at this point.
- The algorithm will be implemented. The algorithm will necessarily take into account the slip frequencies on each side of the opening. This will require integration of the algorithm with a dynamic model.
- Once it has been implemented, the effectiveness of the algorithm will be tested in a lab setting.
- Assuming that the test is passed, we will then seek to deploy the algorithm as part of a utility's or EMS system's black-start methodology.