TCIPG

Comparison of Centrality and Power-Flow-Based Contingency Indices

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Goals

- Attempt to validate graph-theory-based approaches to power system contingency ranking using limited system information (due to the difficulty inherent to acquiring complete system information, a coordinated system attack is more likely to be planned from limited information).
- Develop an approach to identify higher-order contingency scenarios that have a statistically significant likelihood of resulting in a maximally adverse impact given incomplete system information.
- Assist with the development of a test-bed from which attack scenarios can be simulated in real-time, and the resulting data utilized by a vulnerability-related application tool.

Fundamental Questions/Challenges

- We seek to answer the question of whether or not high-impact contingencies can be identified without extensive operational knowledge of a power system. Challenge: conventional contingency screening methods utilize power-flow-based screening techniques requiring knowledge of system branch and shunt impedances, bus MVA injection, and bus voltage magnitudes to check for contingencies that would result in a voltage or branch flow violation.
- We wish to pursue a solution to the question of how to utilize graph theory in the development of an N-X contingency ranking scheme. Challenge: graph-theory-based centrality techniques have not been developed to assess the collective importance of a given group of buses or branches.

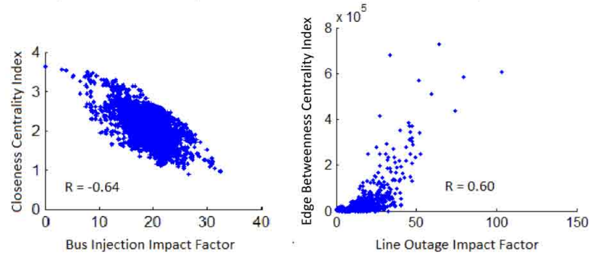
Research Plan

1. Estimate system impedances and topology via physical observation of the power grid or readily available standards information and maps.
2. Calculate degree, eigenvector, closeness, and vertex betweenness centralities for each bus in a power system.
   Calculate edge betweenness centrality for each branch in a power system.
3. Use conventional DC power flow contingency screening techniques to calculate generation shift factors (GSF) and line outage distribution factors (LODF).
   Create DC power-flow-based line outage and bus injection sensitivity indices based on the DC power flow GSF and LODF factors.
4. Correlate centrality indices with DC power-flow-based index to determine which centrality techniques have some statistically significant relationship to an existing contingency screening technique.
5. Using the Wilcoxon signed rank test, determine the agreement in highly ranked contingencies between DC power flow and centrality-based indices.
6. Draw conclusions concerning which centrality technique is the best candidate for developing a topology-based algorithm to identify higher-order contingencies.

Research Results

- Closeness centrality correlates well with a DC power-flow-based bus injection impact factor index, and edge betweenness centrality correlates well with a DC power-flow-based line outage impact factor.

Comparison of Centrality and DC Power Flow Based Vulnerability Measures



- A comparison of the top ten ranked line contingencies for a DC power-flow-based measure and edge betweenness centrality concluded these two ranking systems identified statistically similar top-ranked contingencies across multiple test systems.

Wilcoxon Signed Rank Test for Top 10 Vulnerabilities: Edge Betweenness Centrality Matched to DC Power-Flow-Based Line Outage Index.

Test System	N	Estimated Median	Lower Bound	Upper Bound	Achieved Confidence
IEEE-14	10	3.0	-1.5	7.0	94.7%
IEEE-30	10	5.0	-2.0	11.5	94.7%
IEEE-57	10	6.0	-1.5	10.0	94.7%
Polish-2383	10	5.0	-1.5	58	94.7%

Broader Impact

- Research would result in significant findings for power grid vulnerability analysis using incomplete system information. If graph theory can be reliably utilized to select targets for a coordinated attack on the power system, an attacker can assess the vulnerability of a power system without obtaining confidential power system operational data.
- A graph-theory-based approach to contingency ranking would utilize mathematical tools more familiar to computer scientists, potentially leading to enhanced participation of computer scientists in smart grid research.
- The developed test-bed can be utilized by multiple institutions for further research studies.

Interaction with Other Projects

- Work is inspired by the publication “Electrical Centrality Measures for Electric Power Grid Vulnerability Analysis” from Wang (UI Urbana-Champaign), Scaglione (UC Davis), and Thomas (Cornell).
- Results will serve as an application tool for coordinating cyber attack scenarios simulated with the test-bed being developed using funding from NSF, DOE, and industry partners.

Future Efforts

- Develop a centrality-based N-X contingency ranking algorithm that has a statistically significant relationship with a conventional N-X AC power-flow-based contingency ranking index.
- Investigate whether or not graph-theory-based network flow algorithms are adequate candidates for developing a contingency ranking index.