Decentralized Sensor Networking Models and Primitives for Smart Grid: Part I

Metrics of Grid Vulnerability to Cascading Failures

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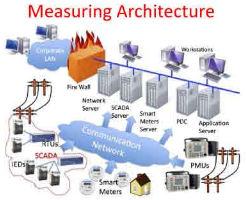
Goals

Cascading failures in power grids are severe security threats. Our goal is to find metrics that use sensor data to identify the critical parts of the physical system that are vulnerable to failure.

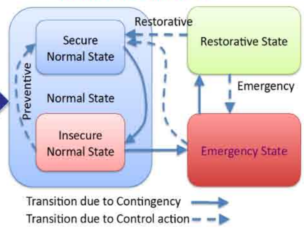
Our new metrics evaluate the risk of cascading failures and the time margin to perform corrective action.

Enhanced Monitoring & Measuring Architecture



NASPI PMU Map

Enhanced System State Awareness for EMS

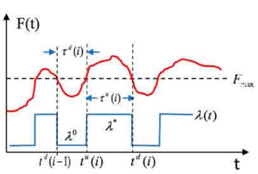


Cascading failures: when, where, and how likely?

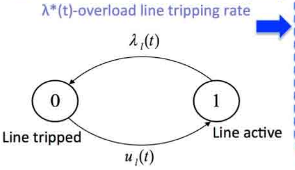
Fundamental Questions/Challenges

- What factors contribute to the grid vulnerability to cascading failures?
- How can we utilize the measurements to determine such factors?
- Can we tell how likely the failure is, and how soon it will occur?
- What are the methodologies to prevent or stop cascading failures?

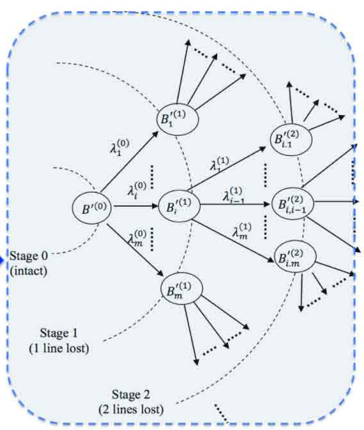
Research Plan



Crossing intervals of line flow F(t) and the transition rates: λ⁰(t)-random contingency, λ*(t)-overload line tripping rate



Line State transitions: line tripping vs. restoration



Markov model

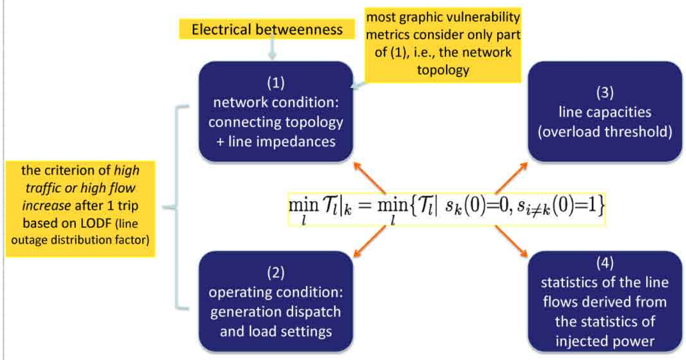
1. Model the grid states as conditionally Markovian on the evolution process of line.
2. Extract the statistics (mean, spatial, and temporal covariance) of generation, loads, and line flows (F(t)), from measurements.
3. Applying the proposed model, we then derive:
   - The probability distribution of level-crossing intervals of F(t).
   - The statistics of the line state transition.
   - The expected active time of each line.
4. Experiments and validation.
   - Vulnerability analysis, simulation package development.

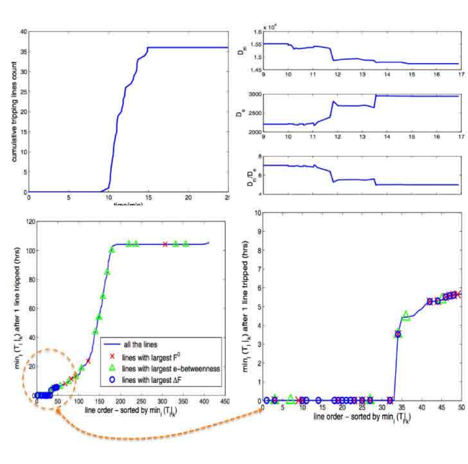
Research Results

- The proposed model computes ***the expected active time*** of a line $\mathcal{T}_l(a_l)$.
- In our experiments $\mathcal{T}_l(a_l)$ is monotonically increasing with the line's overload distance a_l.
- The most critical lines in a network in terms of ***the minimum safety time*** can also be identified as the lines with the smallest overload distance a_l.

$$l^* = \arg\min_l \mathcal{T}_l = \arg\min_l a_l$$

- The time measure of vulnerability takes into account all four affecting factors:





Experiments with IEEE 300 system

$\lambda^* = 1.92 \cdot 10^{-2}$

$\lambda^0 = 7.70 \cdot 10^{-11}$

- The evolution process of cascading failures vs. time.
- With a pattern compatible with historical records from some realistic power grids.
- Correlated line flows in a power grid indicate that the grid is less prone to cascading failures compared to a network composed of independent flows.
- How the (N – 1) contingencies affect the system's minimum safety time, so as to identify the critical set of lines.

Broader Impact

Accurate identification of critical power grid components in terms of cascading failures and **timely prediction** before their advent is one of the main objectives of the cyber infrastructure. We provide a metric to fuse the data and serve these security purposes.

Interaction with Other Projects

This project has close interaction with the projects:

- Decentralized Sensor Networking Models and Primitives for Smart Grid (part 2): State-Aware Database System.
- Secure Wide-Area Data and Communication Networks for PMU-based Power System Applications.

Future Efforts

- Incorporate generation dynamics into the simulation model, use real data on flows, and verify relation between time and overload distance.
- Combine with data processing primitives for fast evaluation.
- Develop wide-area preventive and restorative controls.