An Interaction Model for Simulation and Mitigation of Cascading Failures

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Introduction

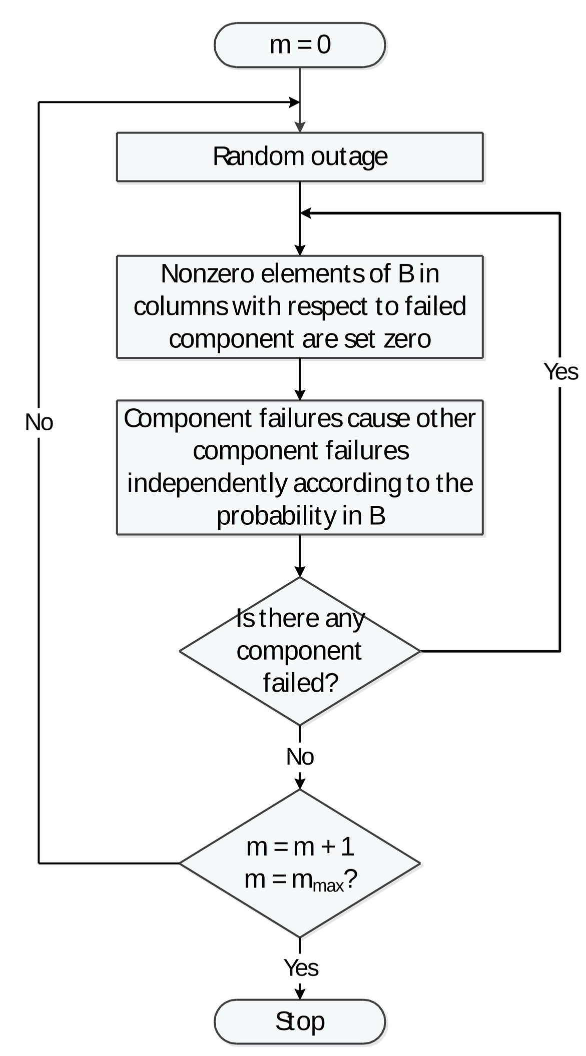
- Cascading blackouts are complicated sequences of dependent outages that lead to load shed. Understanding the mechanism of cascading blackouts are important.
- The interactions between components is the most important reason that cascading failures can happen in power systems
- We quantify the interactions between component by using data that record cascading failure sequences (we use AC OPA model to get original data)

	generation 0	generation 1	generation 2	$\cdots$
cascade 1	$F_0^{(1)}$	$F_1^{(1)}$	$F_2^{(1)}$	$\cdots$
cascade 2	$F_0^{(2)}$	$F_1^{(2)}$	$F_2^{(2)}$	$\cdots$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
cascade M	$F_0^{(M)}$	$F_1^{(M)}$	$F_2^{(M)}$	$\cdots$

- The interactions are denoted by conditional probability that the failure of one component causes the failure of another component; further we can get an **interaction matrix *B*** containing the conditional probability
- The interaction matrix summarizes how the cascading outages are correlated and by using this information we propose an interaction model which can speed up the simulations

Interaction Model

- **Utilize the information in interaction matrix**
- **Model design**



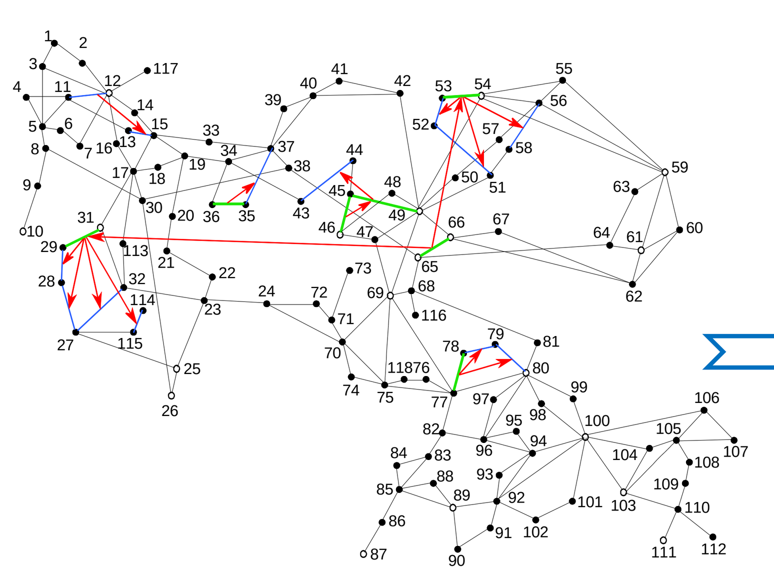
- Step 1: Accidental faults of components (severing as trigger of cascading failure)
- Step 2: Corresponding columns of B are set zero (once a component fails it will remain that way)
- Step 3: The component failures in one generation independently generate other component failures according to the probability in ***B***

❖ The interaction model can be used to study how interactions influence cascading failure risk and quickly find out how the weakening of some interactions can help mitigate cascading failure

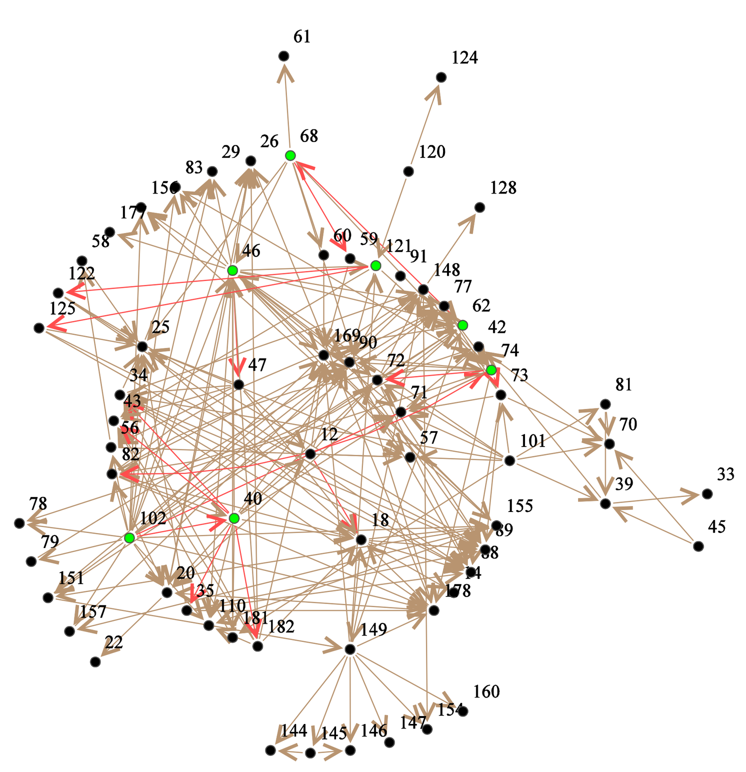
Results

Quantifying Interactions

- The interaction matrix ***B*** can be denoted by an interaction network whose links correspond to the nonzero elements in ***B***
- The interaction network



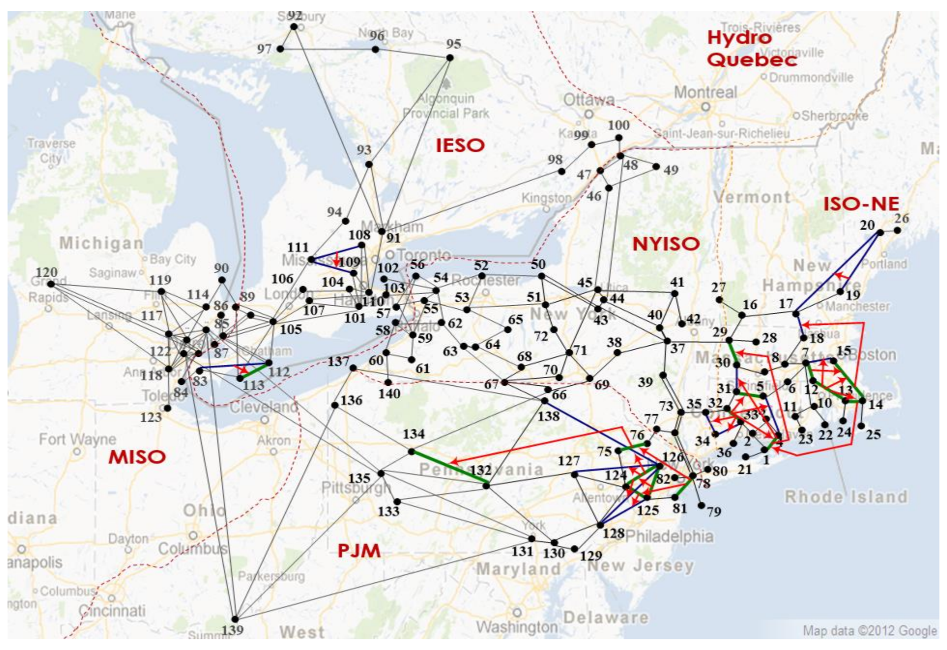
Topology of IEEE 118-Bus System

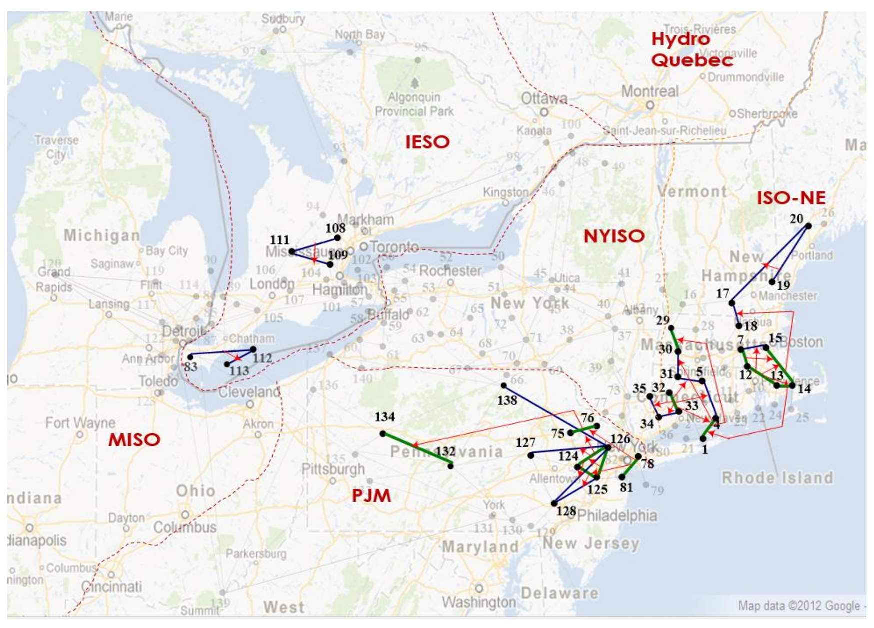


Interaction Network of IEEE 118-Bus System

- Based on the quantified interactions, define an index to indicate the spreading capacity of a link in the interaction network and identify key links that play key roles in the propagation of cascading
- Mitigation can be weakening the key links to prevent failure propagation

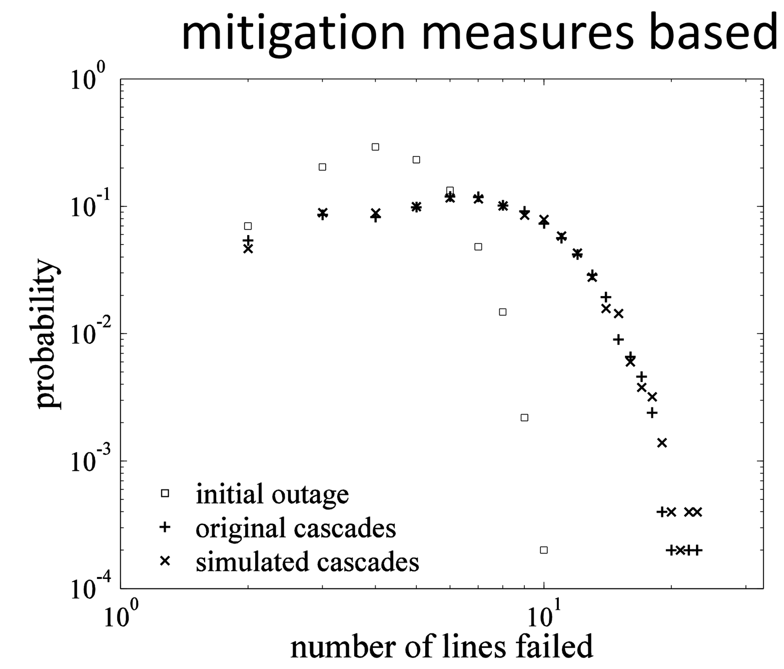
- Test on NPCC 140-bus system
  - 15 key components (6.43%): total out-strength ~ 68.8% of the system
  - Key links (0.7%): total weight ~ 38.5% of the system



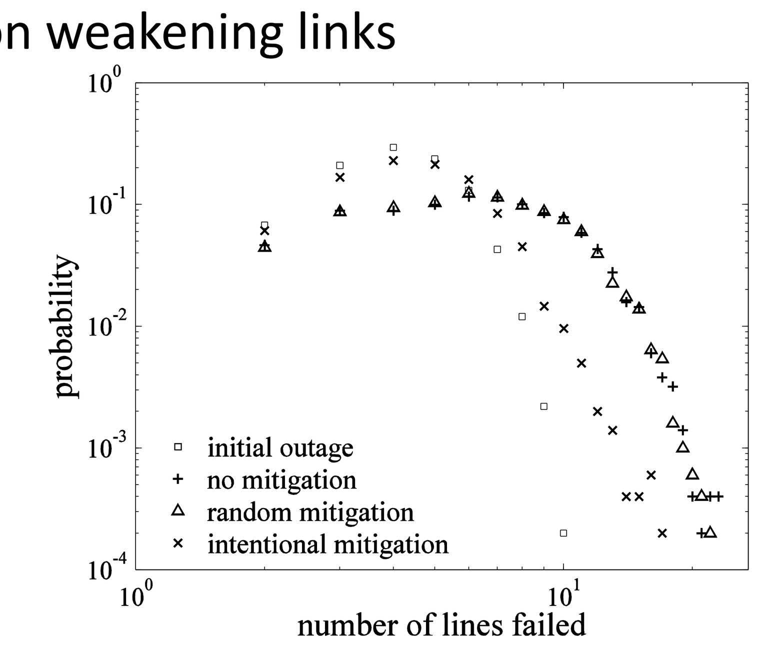


Interaction Model

- We use the interaction model to generate the same number of cascades as the original cascades and compare their probability distribution
- By using interaction model we can also investigate different mitigation measures based on weakening links



Comparison of PDF from Original and Simulated Cascades



PDF under Different Mitigation Strategies

Conclusion

- The interactions between components are obtained by calculating the conditional probability that one component failure causes another
- The interaction quantifying method and interaction model are validated to be able to capture general properties of the original cascades.
- Cascading failure risks can be greatly mitigated by weakening a few key links, which can be implemented in real systems by wide area protection that blocks the operation of relays of the lines corresponding to the destination vertices of key links when the lines corresponding to the source vertices are tripped

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