Cascading Failures in AC Power Grids

Martin Rohden
in collaboration with Daniel Jung, Samyak Tamrakar and Stefan Kettemann

Department of Physics & Earth Sciences
Jacobs University Bremen

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Challenges for Power Grids

Typically, the blackout can be traced back to the outage of a single transmission element. (FAZ, “Grenzenloser Stromausfall”, 06.11.2006. P. Pourbeik, P. Kundur, Taylor C., IEEE Power and Energy Magazine, 4. 22-29 (2006).)
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Cascading Failure Algorithm

- Determine the system’s steady state with power flows $F_{ij}$
- Delete a single transmission line
- Determine the new steady state with updated power flows $F'_{ij}$
- If $F'_{ij}$ is larger than a threshold value $F_{th}$:
  - Delete transmission lines with $F'_{ij} > F_{th}$
  - Calculate new power flows $F''_{ij}$ and proceed with previous step
- Stop when either no line is overloaded or the network disconnects into different islands
- Count the number of disconnected consumers $N_C$
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Step 1: Deleted transmission line is marked in red.

Step 2: Second transmission line becomes overloaded.

Step 3: Network disconnects into different islands.

(a) Linear relation between cluster size and disconnected consumers.
(b) Less critical links for large clusters.
More cascading failure events with decreasing thresholds.

No direct relation between cluster size and disconnected consumers.

Large outages are present for large thresholds.
Square Grids: Random Distribution

- Qualitatively similar behavior for all considered thresholds.
- Larger system size leads to larger possible outages.
Middle regime: fit to scaling function $\bar{p}(N_c, L)$ with

$$\bar{p}(N_c, L) = N_c^{-q} \cdot f \left( \frac{N_c}{L^d} \right)$$
Qualitatively similar, but $\bar{p}(N_c)$ has small steps.
Cascading failure algorithm based on synchronous motor model
- For periodic consumer distribution mostly one cluster becomes disconnected
- Random consumer distribution: no direct relation between consumer clusters and disconnected consumers
- Square grids: we find a scaling function with system size
- German power grid: Qualitatively similar, but due to heterogeneous topology $\tilde{p}(N_c)$ possesses small gaps
Acknowledgements

Thank you for your attention!