

Can cascading failures be eliminated?

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March, 2006

Why do cascading failures happen?

Cascading failures are the emergent and unintended consequences of the protection policy:

- assign thresholds to devices**
- use distributed autonomous agents (relays) to remove devices from service when their thresholds are crossed.**

A dozen properties of cascading failures...

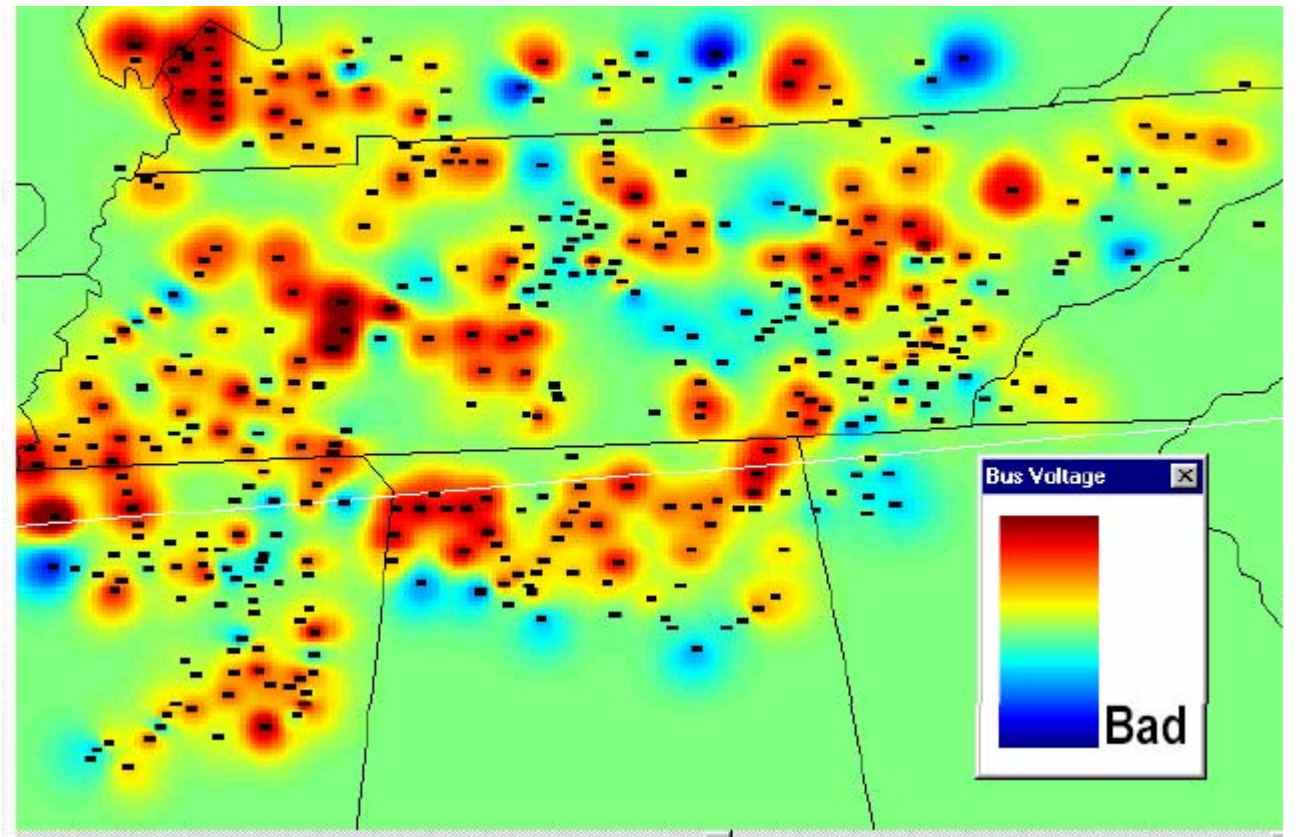
Property-1: The social costs of cascading failures are of the order of 10 billion dollars per year—large but not overwhelming.

Statistics for 1984-2000 from the North American Electric Reliability Council:

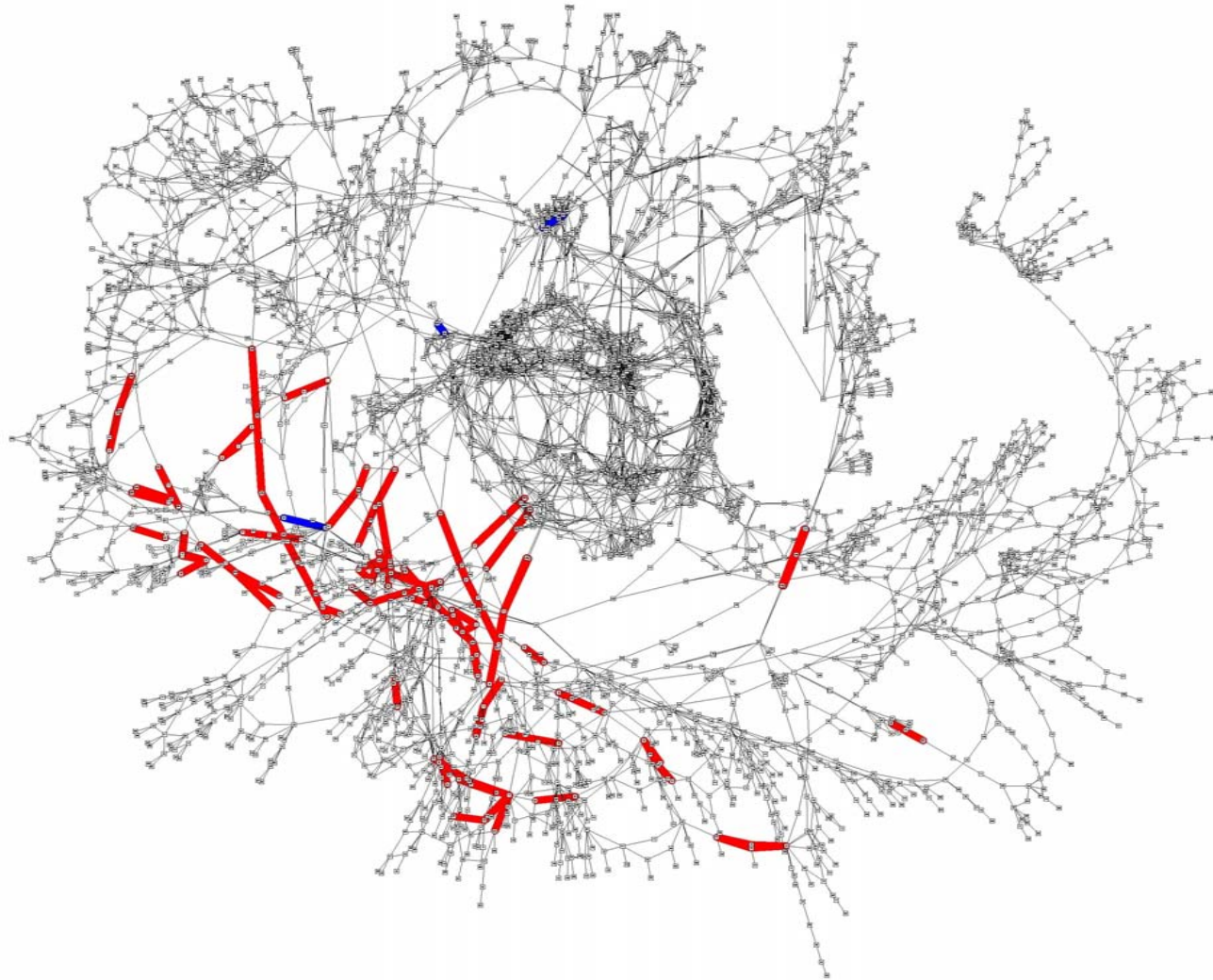
- **533 transmission or generation events**
- **324 (1 every 19 days) had power losses ≥ 1 MW**
- **46 of these (3 per year) were ≥ 1000 MW**

Property-2: Pre-cascade stress--the proximity of state variables to thresholds--varies with time and location.

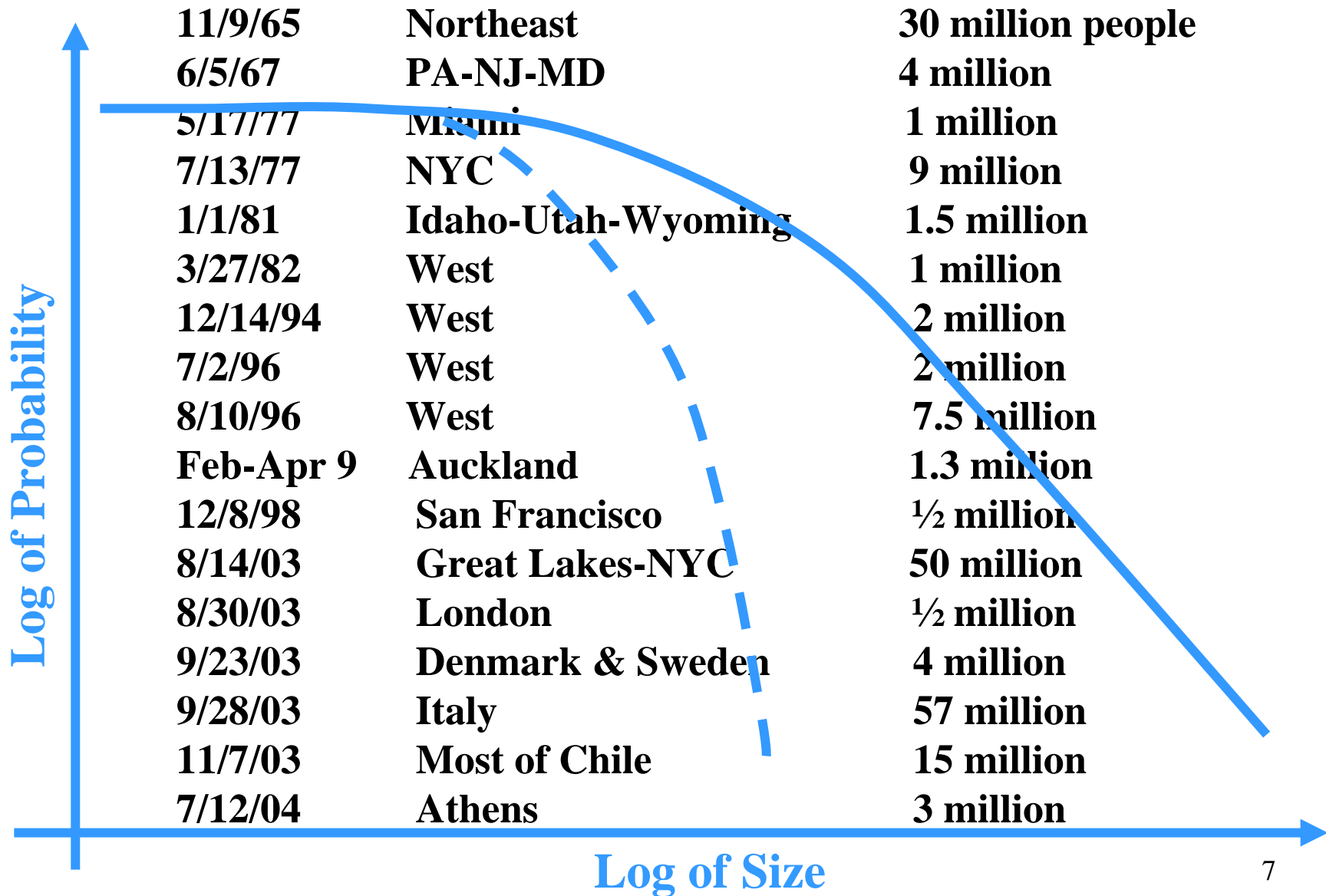
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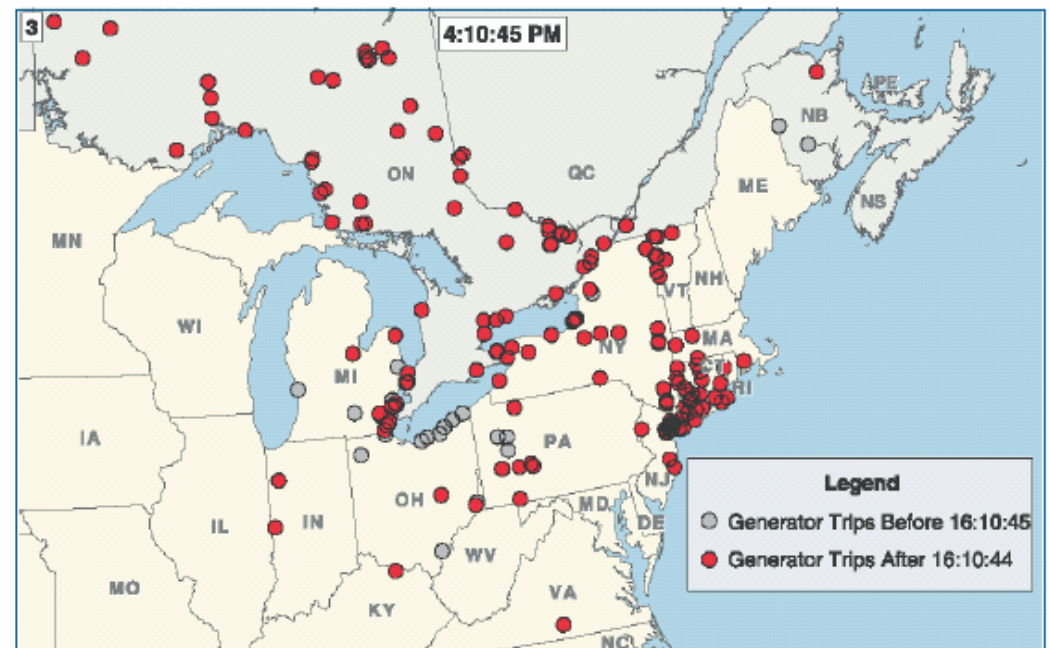
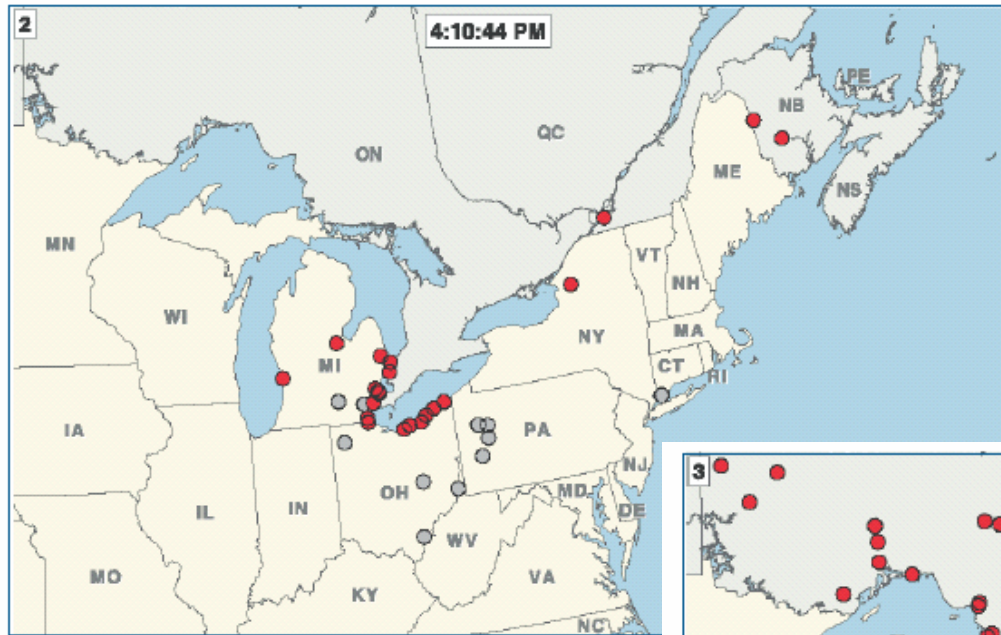
Property 3: It takes high stresses and a multiple contingency to start a cascade



Property-4: These conditions happen often enough to give the distribution of blackouts a fat tail



Property 5: The failure front (the next set of device removals) can move too fast for human intervention

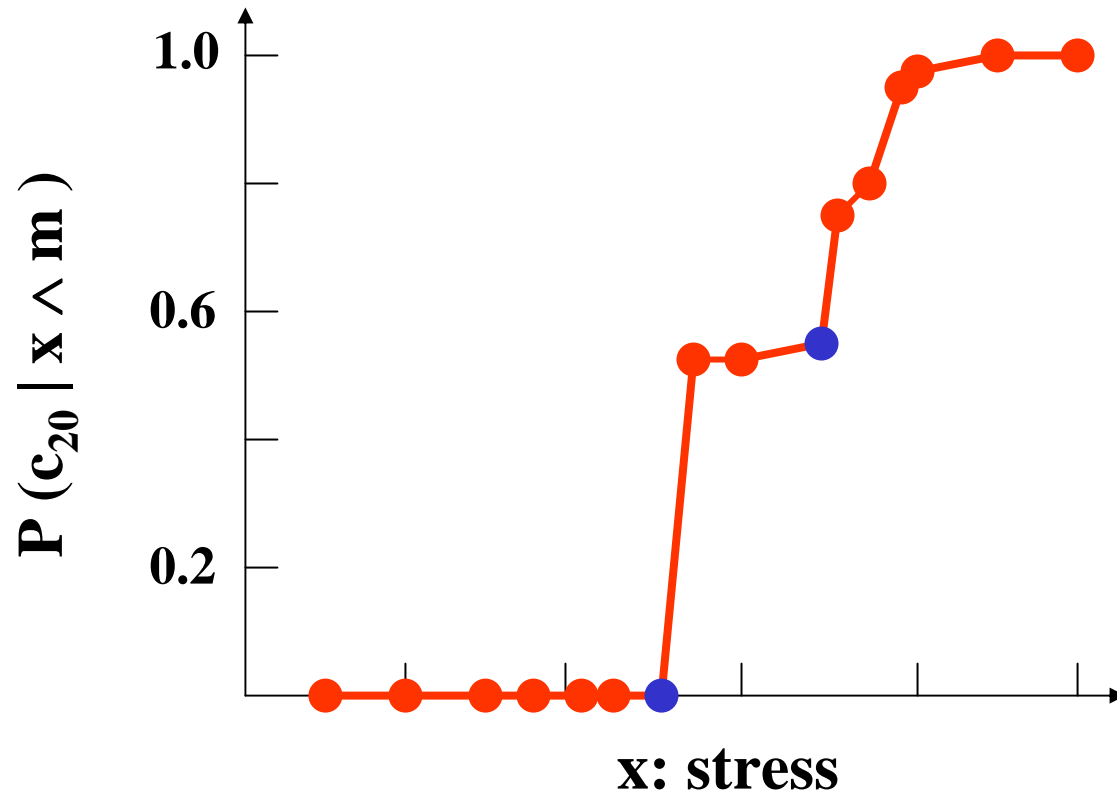


About 100 generator trips in one second

Property 6: But cascading failures are self-limiting



Property 7: There are critical points along many, if not most, trajectories through state space, along which stress increases monotonically. The probability of cascading failures increases abruptly at a critical point.

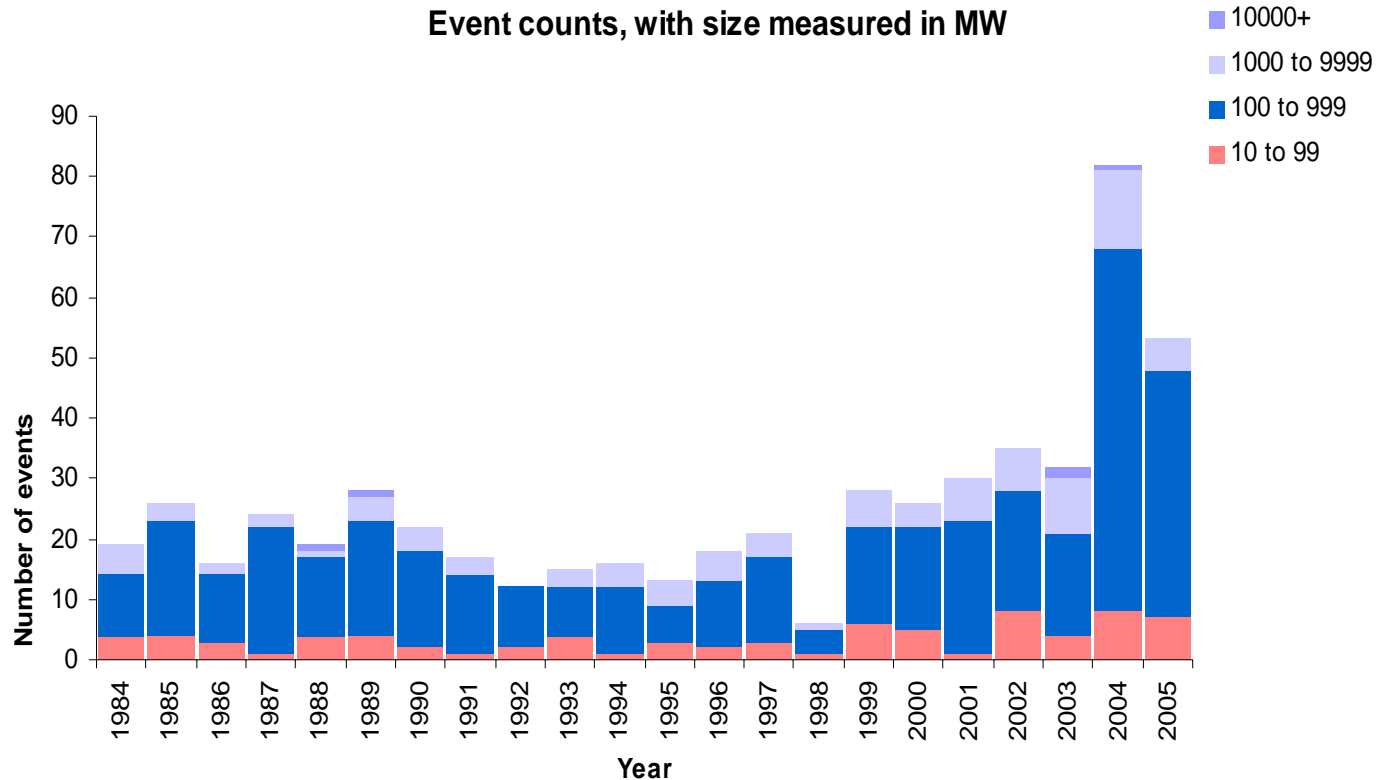


Property-8: Both short-and long-range effects are involved in the propagation of the failure front.

Relay and other control system malfunctions play an important role in propagating the failure front

More complex protection policies will increase the likelihood of malfunctions, unless the policies are carefully verified.

Property 9: Investments in equipment and new technologies have not reduced the frequency or impact of cascading failures



Property-10: The social costs of cascades can be drastically reduced

Post-cascade analysis invariably reveals several different and relatively inexpensive actions, any of which would have shortened the cascade, had the actions been taken soon after the cascade began.

These actions are cascade-specific. We believe they can be calculated in real-time, quickly enough to be useful.

Property 11: Electric power networks are stochastic hybrid systems. Their operation involves:

- **Contingencies and other uncertainties**
- **Continuous variables**
- **Discrete variables**

If optimal-cascade-stopping actions are to be calculated in real-time, then:

- **the network's hybrid characteristics must be taken into account**
- **the overall problem must be formulated as one of minimizing social cost while protecting equipment**

Property 12: There are neither rigorous nor centralized algorithms for solving the overall problem.

If good solutions are to be obtained, then:

- good decompositions into sub-problems, one for each autonomous agent (relay), must be found.**
- the limits of the verification procedure must be well understood.**

Can cascading failures be eliminated?

No!

Not unless operators are prepared to keep networks at stresses well below their ratings, and new techniques are discovered for verifying all possible contingencies.

But we can do a lot better than the existing protection policy...

Before a cascading failure happens we can....

- 1. Estimate the risk**
- 2. Suggest actions with Pareto optimal tradeoffs between risk-reduction and action-cost.**

After a cascading failure has started we can....

Use distributed autonomous agents (more intelligent relays) to implement a protection policy with much lower social costs