Criticality and Risk of Large Cascading Blackouts

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Background

- Managing the risk of large blackouts is vital to the United States.
- Large blackouts typically involve complicated series of cascading rare events that are hard to anticipate in detail.
- We can now exploit the new models and ideas we have developed since 2001 within CERTS to address the risk of large blackouts caused by cascading failures from a global, complex systems perspective.

Project History

FY01-02

Team: ORNL and PSERC (Wisconsin,Cornell)

Budget: 100K per year

FY03-04

Team: ORNL and PSERC (Wisconsin)

Budget: 110K per year

Close collaboration between national lab and universities

LEVERAGE: Collaboration with University of Alaska

Funding from NSF

Goal

Contribute to transmission system reliability by

Understanding large, cascading failure blackouts and providing tools for analyzing and monitoring their risk.

In particular, the project will identify the threshold that leads to increased risk of cascading failure, express this threshold in terms of realistic power system parameters and develop monitoring tools and criteria to be applied in real power transmission systems.

Stakeholders and Impact

- **DOE:** risk analysis and tools to assist regulatory process
- **Power industry:** tools and operating criteria to help manage risk
- **Engineering and science communities:** problem formulation, insights, and analysis
- **Business and the public:** contribute to reliability, education

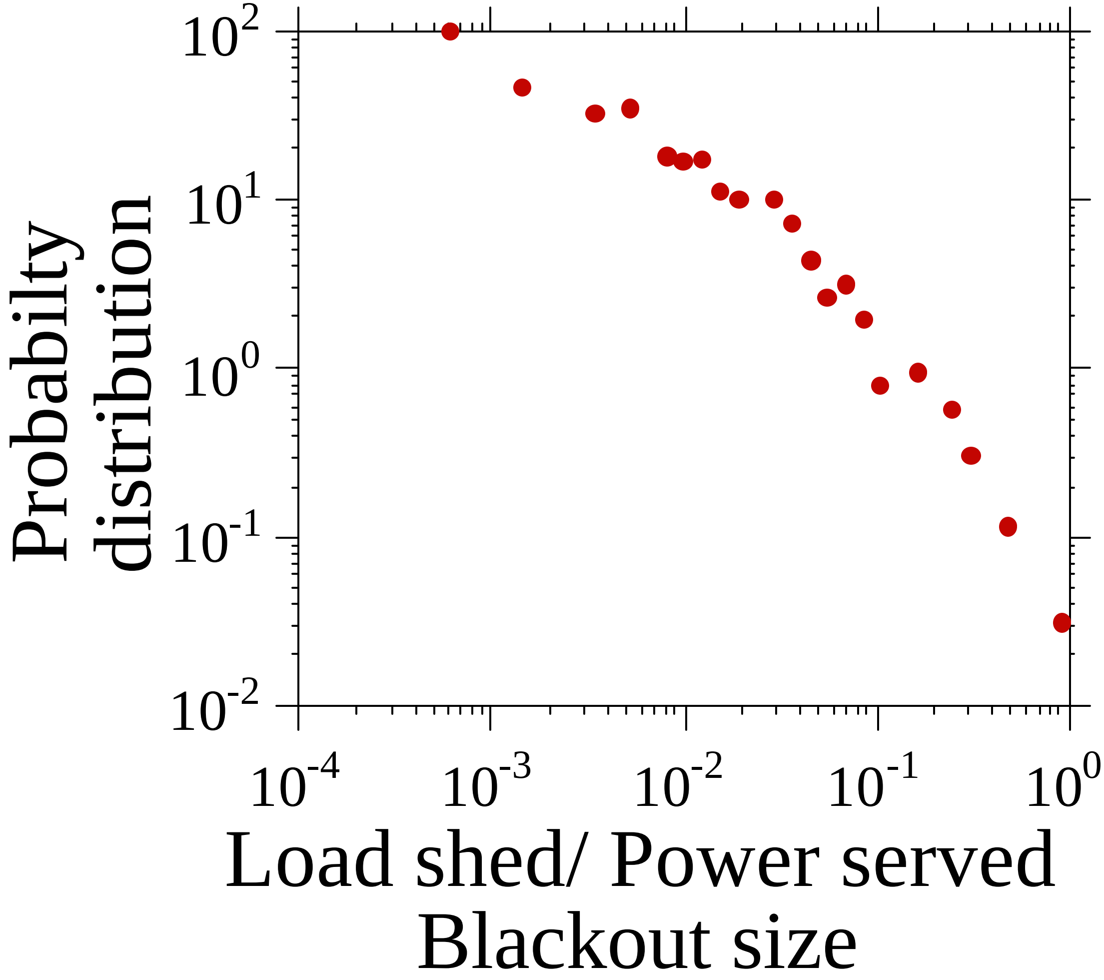
- **Impact:**

Technical: 8 conference papers, 4 journal paper

Public: Quotes and background provided to over a dozen newspaper articles; appeared on NPR radio and ABC Nightline. Project research results featured in Nature, National Post, Energia, and SIAM News.

NERC blackout data shows power tail

- Large blackouts more likely than expected
- Conventional risk analysis tools do not apply; new approaches needed
- Consistent with complex system near criticality
- Large blackouts are rare, but have significant risk



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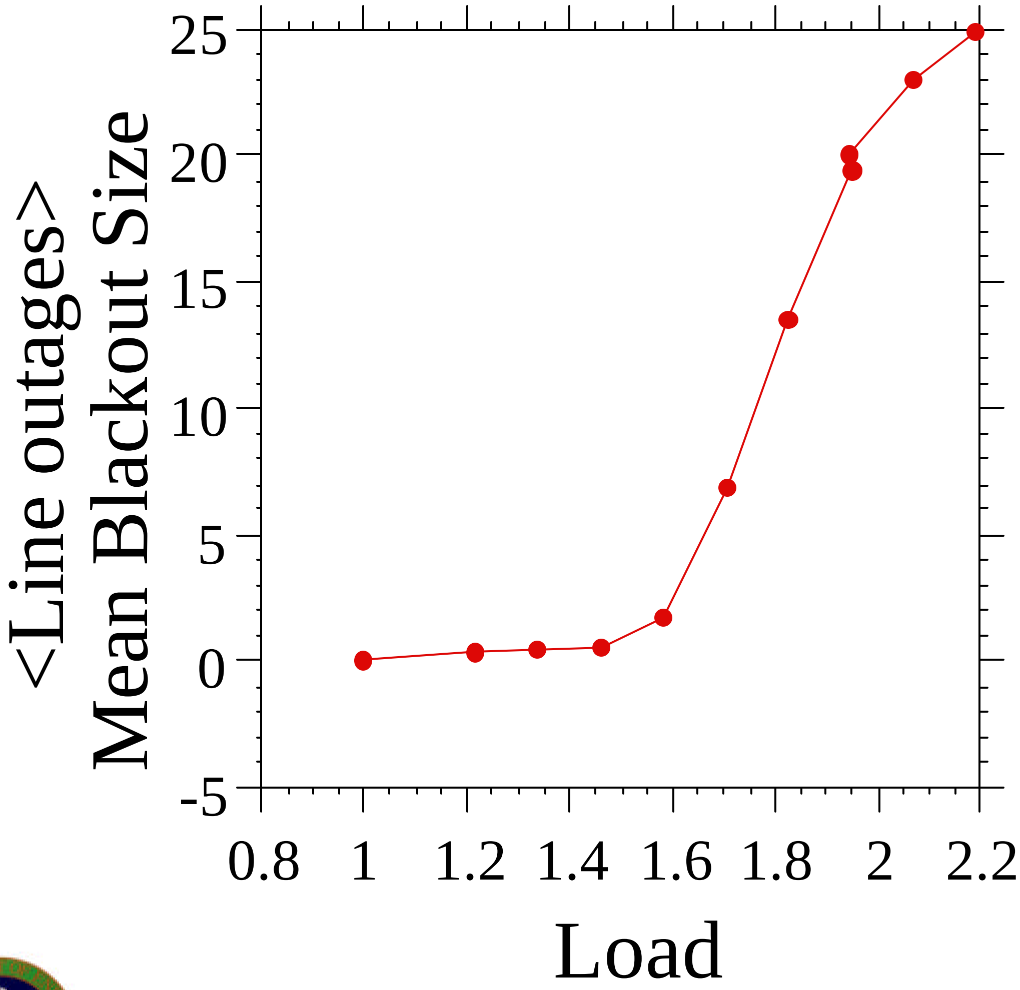
OPA Dynamical Model

OPA is a power systems blackout model including cascading failure and self-organizing dynamics

- transmission system modeled with DC load flow and LP dispatch
- random initial disturbances and probabilistic cascading line outages and overloads
- underlying load growth + load variations
- engineering responses to blackouts: upgrade lines involved in blackouts; upgrade generation; "blackouts cause reliability"

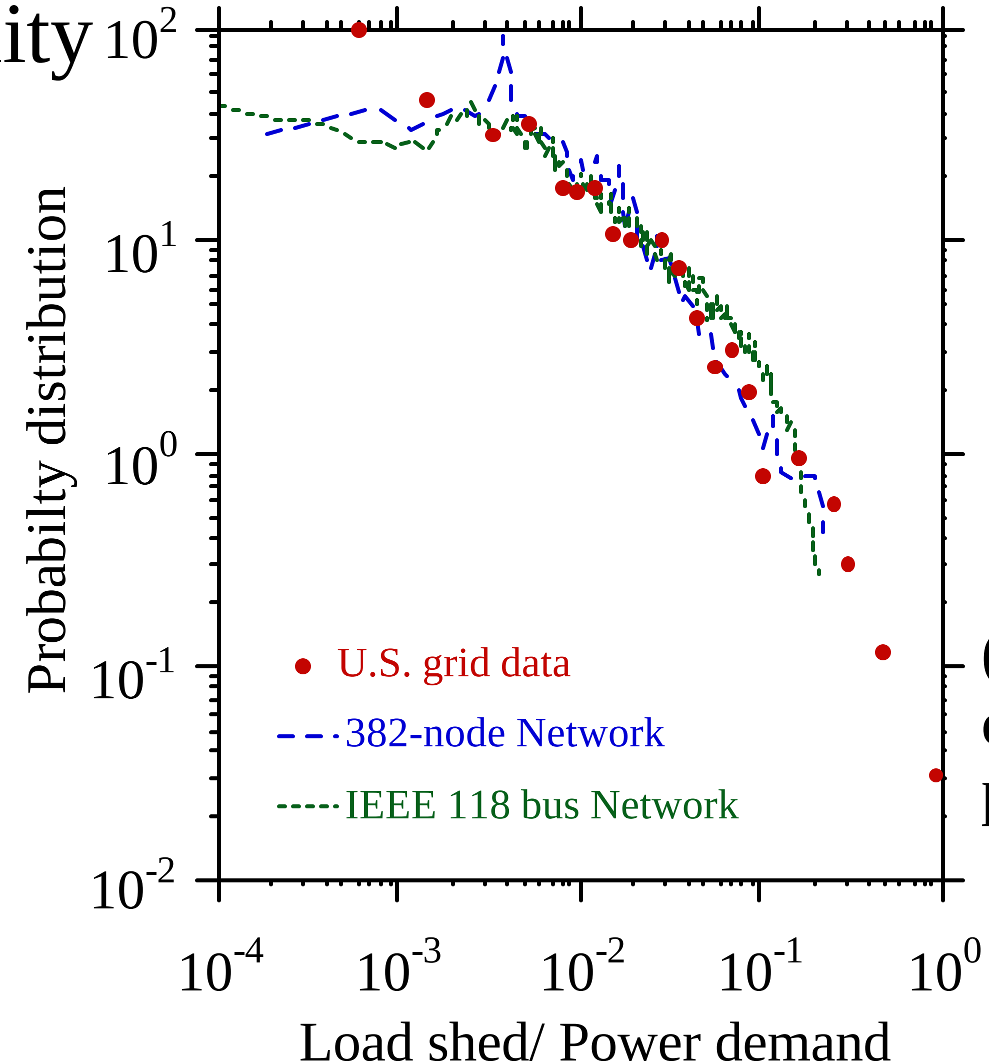
Critical loading: threshold for cascading failure



Mean blackout size sharply increases at critical loading; increased risk of cascading failure.

OPA can match NERC data

probability



(August 14 blackout is consistent with this power tail)

blackout size

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Significance of OPA

- Existence of critical loading with increased risk of cascading failure
- Engineering and economic forces can self-organize to near criticality
- Consistent with NERC data
- Sensible mitigation methods can reduce frequency of small blackouts while increasing frequency of large blackouts.
  Need to jointly manage **both** small and large blackout risk.

ongoing and future work on OPA:

- Test bed for monitoring and understanding criticality and risk
- Improve power system and engineering/economic modeling

CASCADE model

- Probabilistic model of loading-dependent cascading failure.
- Captures salient features of cascading failure in an analytically tractable form.
- CASCADE shows a critical threshold loading with power tails, sharp increase in mean failure size, and an increased risk of cascading failure.
- Approximations to CASCADE give insights into failure propagation and criticality.

Current work

- Study OPA and CASCADE to gain a deeper understanding of the critical loading, the parameters controlling it and to monitor cascading failure propagation.
- Key idea: approximations to CASCADE suggest that failure propagation is governed by a parameter λ
- $\lambda = 1$ gives criticality
  $\lambda <$ safety margin < 1 gives reduced risk of cascading failure
- Current work aims to define and measure λ in OPA

Path to a practical monitoring tool to manage cascading failure risk

- Use OPA to thoroughly understand the critical loading threshold that causes increased risk of cascading failure.
  Test and refine metrics for monitoring closeness to criticality such as

  – Failure propagation parameter λ

  – Total load transfer for a failing line: $$l_{0j} = \frac{1}{M_j^0}\sum_{i=1}^{\overline{N}_L}\left(M_i^1 - M_i^0\right)$$

  where M is the fraction of line overload.

  – Loading margin to L to critical loading

- Determine the secure conditions of operation. How close to criticality can one operate?

Path to a practical monitoring tool to manage cascading failure risk

- Use previous results to develop criteria and measurements applicable to real system.

- Explore the development of software tools to monitor power system security with respect to large cascading failures. First test these tools in simulated operation to assess their capabilities and limitations.

- Implement the tools and criteria to monitor power system status, and risk trade-offs and do “what-if” analysis. We will pursue collaborations within CERTS to develop these practical tools.

Summary

- Transmission reliability requires all aspects of cascading failure to be understood and appropriate criteria and tools to be developed. The sole use of the deterministic n-1 criterion is not enough.
- We need to find out "where is the edge for increased risk of cascading failure?" and need to manage risk tradeoffs.
- Our approach is global and top-down and is complementary to detailed analysis of particular blackouts.
- Our approach aims to provide practical tools and criteria for monitoring closeness to an increased risk of cascading failure.