Complexity, Intelligence and Resources of the Electric Grid

by John G Schwitz, November 19, 2012

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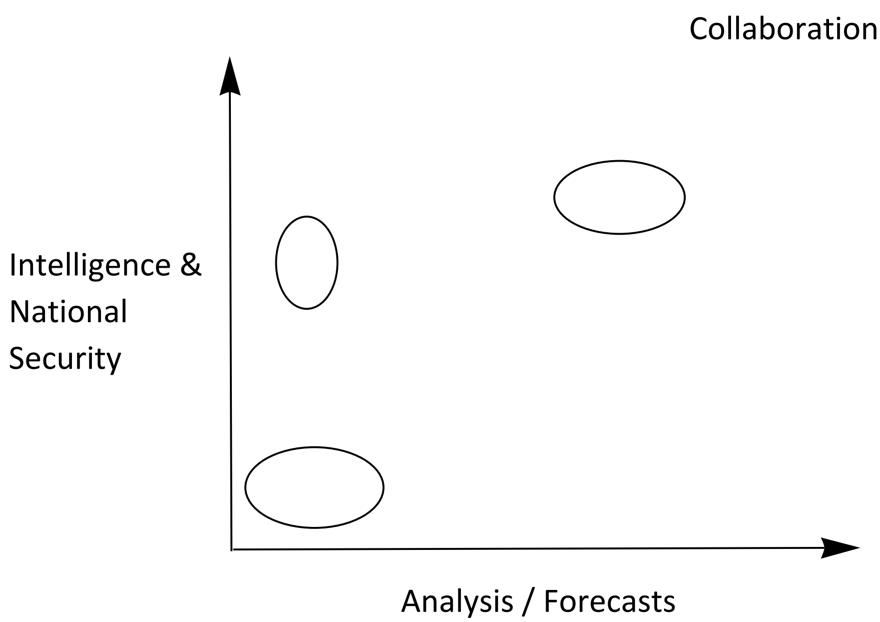
Intelligence, National Security, and Collaboration

TERMS: Cascading Failures / Isolated Islands / Scale-free Networks (Power Law) / Complexity
Tripped Relays / NOT damaged Generators

SOURCES:
Electric Grid is Complex Process / Extensively Studied
Major Blackouts NERC/FERC
- Arizona-Southern California Outages September 8, 2011
- United States Canadian Blackout (largest in US) August 14, 2003

Future of Electric Grid -- MIT Study
Risk analysis of critical loading and blackouts with cascading events -- CERTS / Ian Dowson
Baraba'Lab (complexity, self-organized criticality {soc}, networks)



Frequency of Events -> Power Law -> Black Swan Events

Frequency of Events of degree d

In many domains this yields a Power Distribution:

{earthquakes, forest fires, traffic congestion, disturbances on electric grid, transmission of biological & computer viruses, diseases, and fads}

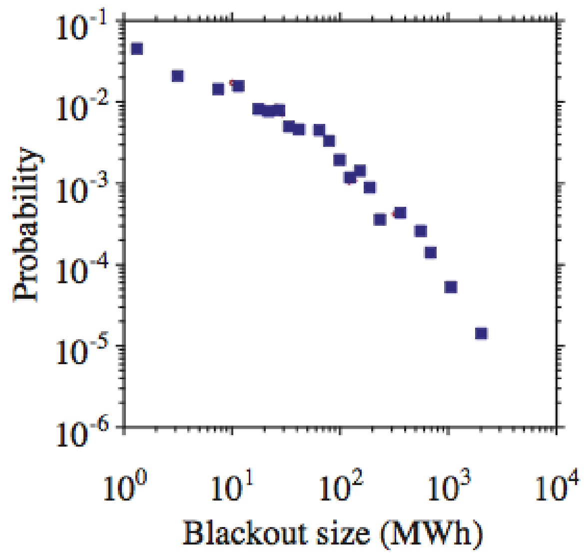


Fig. 1: Log-log plot of scaled PDF of energy unserved during North American blackouts 1984 to 1998.

self-organized criticality (soc), chaos theory, small world networks, complexity theory

The basic idea is that certain structures evolve through internally and externally driven processes toward a critical state. There is no architect or master plan. There is no reductive physics explaining the process. The differentiating feature of a critical state is its response to disturbances.

A normal state responds, within a narrow range, with a characteristic response time and scale. A critical state is scale-free. It responds to disturbances with time and scale responses of any size.

Exponential Distribution $y=x^k$ Yields $\log[y] = k \log[x]$ For $k = -1$

Increasing the degree (magnitude of event) by 10x reduces frequency by only 1/10'th

Connectedness, Infinte Variance and the Power Law

A Power Law describes the scale of response statistically. A Power Law is a different beast because it has infinite variance. Power Law only applies over a restricted range.

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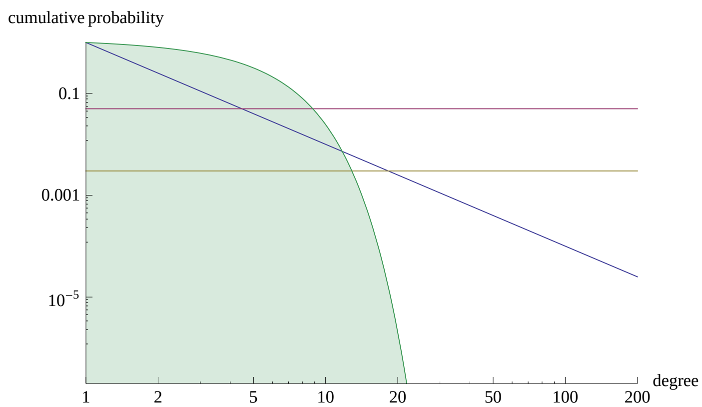
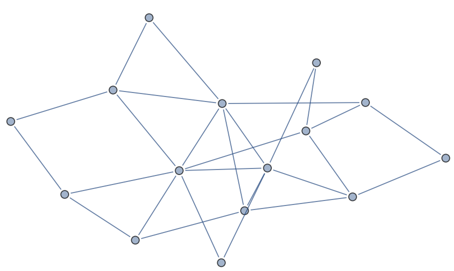
Comparison of Power Law to N(1,4)

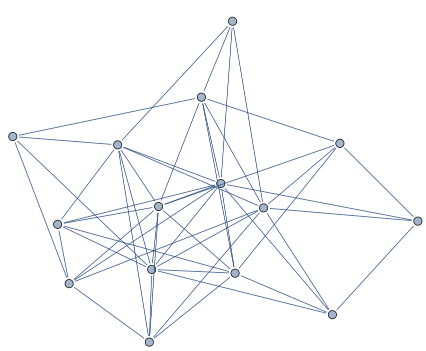
1σ (5) is 68%, 2σ (9) 95%, 3σ (13) 99.7%
x axis at 6σ /   range limited to 200



Network Connectedness Resulting in Vulnerabilities



2 Connections



4 Connections

Robustness to Random Failure / Vulnerability to Attack

(LEFT) Theoretical behavior of Network Diameter (d) and Cluster Size (C) under Random Failure & Attack for Scale-free network.
(RIGHT) Cascading Failures and Isolated Islands in largest US Blackout (2003)

Critical infrastructure is robust under random failure, but extremely vulnerable to destruction under attack.

Figure 6: Network diameter vs. failure rate [5]

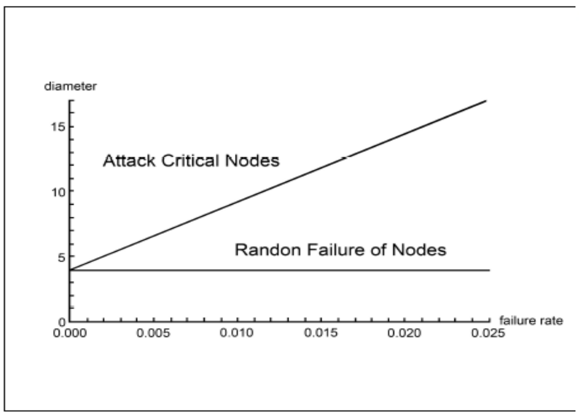


Figure 7: Cluster Size by Failure Rate [5]

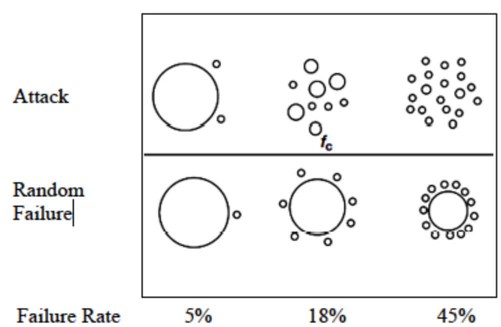
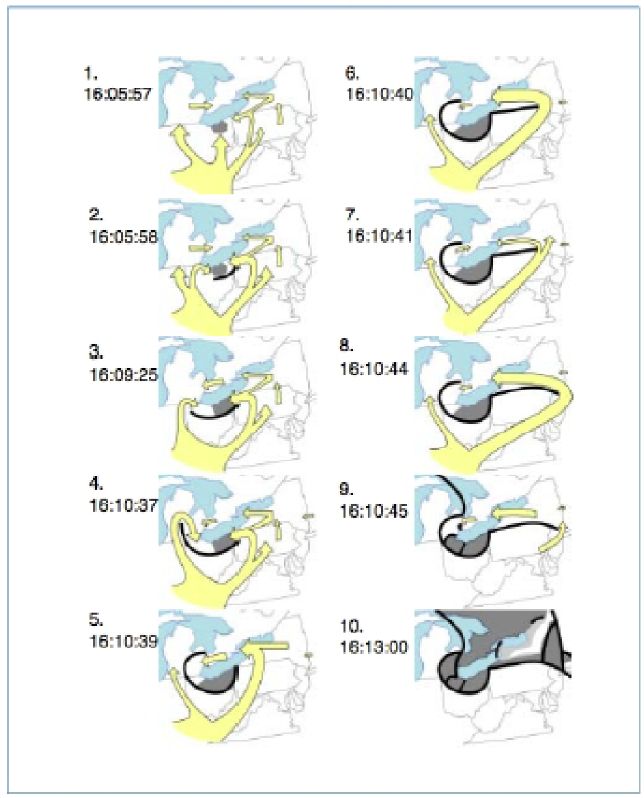


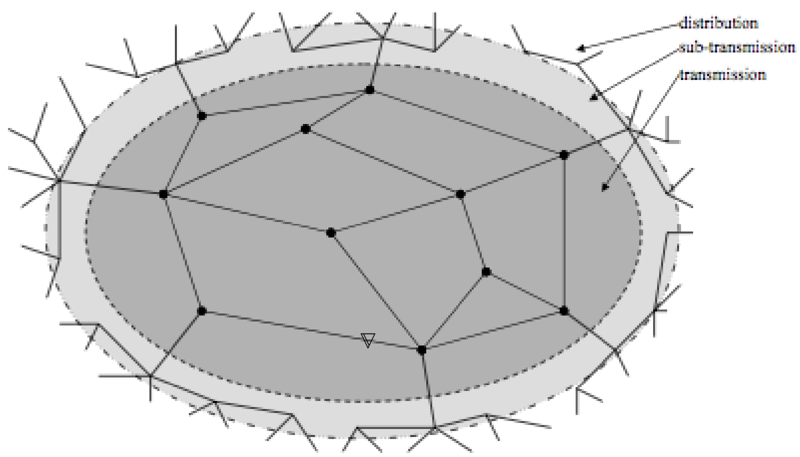
Figure 6.30. Cascade Sequence



Characteristics of Electric Grid {Components, Structure, Statistics}

The Electric Grid's three components {Generation / Transmission / Distribution} and
3 Interconnection Systems {Eastern / Western / Texas} / Transmission Scale-Free Network

$1 Trillion Asset Value / 200k miles 230k Volt and higher / 950k MegaWatts Generation / managed by 140 Control Areas /3,500 Utilities / serving 100M customers and 283M people / Grid saves $13B annually



Transmission network is a mesh (dark gray), while Distribution (light gray & white) are mainly radial. Transition system modeling uses Distribtution (light gray) as the boundary nodes.

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