The Future Power Grid
Resilience and Systemic Risk

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FLOODING IN THAILAND COULD CAUSE INDUSTRY-WIDE HARD DRIVE SHORTAGE

BY AMY FREELAND / 31 OCTOBER 2011 / 0 COMMENTS

Heavy monsoon rains that have left much of Thailand literally under water could impact the computer industry this holiday season and beyond. According to All Things D, the flooding already has affected the Thailand operations of two major hard drive manufacturers, Western Digital and Seagate Technology.

The New York Times

December 27, 2008

Flight Delays Radiate From Chicago and Atlanta

Major power outage hits New York, other large cities

August 14, 2003
Economics

- Power outages cost US economy $80B -150B annually (0.01 % of GDP)
Efficiency and Reliability

- Efficiency and reliability at the component Level

- Efficiency and Reliability at the system level
  - Information and Decision Architecture
    - Modeling and simulation
    - Communication and Control Architectures
  - Market Architecture

- Incentives for Innovation
  - Regulation
Efficient Components

• Energy usage divided among sectors
  • Residential ~ 37%
  • Commercial ~34%
  • Industrial ~26%
  • Transportation ~ (currently) small

• Efficient power electronic Components
  • More effective lighting (e.g., LED lighting), air conditioning (e.g., high-efficiency inverter-driven AC), appliances (reduced standby power, higher efficiency), etc.

• Improved electronic controls, sensing and communication, and management offer substantial demand-side control
System Level Reliability-Resilience

- Robust communication and control architecture

- Caveats:
  - Feedback (e.g., Real-time demand response)
  - Coordination vs Strategic (e.g., demand shift)
  - Network effect
Price Volatility

Locational Marginal Prices at PJM ISO 07-April-2011 12:40 EST

This image will be refreshed in 2 Minutes, 3 Seconds. Please hit ctrl-F5 to manually refresh this page.
Price Volatility

Locational Marginal Prices at PJM ISO 07-April-2011 12:45 EST

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Price Volatility
Locational Marginal Prices at PJM ISO 07-April-2011 12:50 EST

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Price Volatility

Locational Marginal Prices at PJM ISO 07-April-2011 12:55 EST

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Price Volatility

One Hour Later...
Price Volatility
Locational Marginal Prices at PJM ISO 07-April-2011 13:45 EST

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Price Volatility
Locational Marginal Prices at PJM ISO 07-April-2011 13:50 EST

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Price Volatility
Locational Marginal Prices at PJM ISO 07-April-2011 13:55 EST

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Price Volatility
It does get even more dramatic...

There are many examples like this.
Real-Time Demand Response
Closing the Loop

ISO

Dispatch

Demand prediction

wind

d_t

Consumer Model

Supply Schedule

Locational marginal price
RTP Increases Volatility
Price of Coordination

• Price of Anarchy: Loss in efficiency due to strategic interactions in contrast to a coordination

• Simple model: one agent with shiftable demand and another with instantaneous demand

• Contrast optimal efficient solution to a Stackelberg game of strategic behavior

• A new tradeoff: Cooperation can increase endogenous risk
Price of Anarchy: what about risk?

Aggregate demand

Cooperative
Strategic

Variance

Sample path

 Aggregate demand

Cooperative
Strategic

Variance

Sample path

Aggregate demand

Cooperative
Strategic

Variance

Sample path
Example 1: $L = 2$

95% percentile

Stationary distribution

Aggregate demand

Cooperative
Strategic
The elasticity of consumers and producers is such that the interactions at each node are very stable.
Due to heterogeneity, interactions between a consumer and a producer at a different bus may be unstable or “less stable”.
Increasing the transmission capacity between 1 and 2 amounts to interconnecting dynamical systems.
Innovation

- Robust Architecture (Distributed vs decentralized)
  - Robust Feedback
  - Distributed computing, Strategic decisions
  - Network effects and Resilience

- Degree of Regulation and Centralization

- Incentives
  - Who owns what?
  - Can renewables be penalized?
  - Storage

- Electrification of cars
Thank You
Economics

- Power outages cost US economy $80B - 150B annually (0.01% of GDP)

- The number of outages of 100 MW or larger is up from 78 during 1995-1999 to 147 during 2000-2004, and to 250 during 2005-2009.

- The number of outages affecting 50,000 or more customers has a similar pattern of steady increase.

- Other surprising risks: Network effects and coupled infrastructures (The Germany Case).
Tradeoff

Efficiency
(- variance)

Robustness
(1- tail probability)

strategic ← ↑ complementarity ↓ → cooperative

-150

-100

-50

-10

0

0.1

0.2

0.3

0.4

0.5

0.6

0.7

0.8

0.9

1

0.95

1

0.5

0.6

0.7

0.8

0.9

1

Massachusetts Institute of Technology
Electrical Energy Usage in the USA

- Energy usage divided among sectors
  - Residential ~ 37%
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