Increasing the Security & Reliability of the USA Electricity System

Lester Lave, Jay Apt, & Granger Morgan
Goals: 1. Lower the likelihood of blackouts using cost-effectiveness & benefit-cost approaches
2. Minimize social cost & disruption if a blackout occurs

Blackouts can result from natural hazards, human mistakes, or terrorists
Our economy & lifestyles are completely dependent on electricity
Would Blackouts Cause Terror?

Backouts are common: Most people lose power once or twice a year for a few minutes.

Even large blackouts are familiar.

People are not terrified, but there can be crime & arson: New York in 1977.

Blackouts stop almost all economic activity and so are extremely costly.
Hypothesis: Perhaps 90% of Protecting the Electricity System Against Terrorism is Gotten from Protecting the System against Natural Hazards & Human Error

We don’t know if terrorism will ever threaten the US electricity system
We do know that reliability is a major social cost
Our first major challenge is increasing reliability
### Some Recent Large Blackouts

<table>
<thead>
<tr>
<th>Date</th>
<th>Location</th>
<th>Affected Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/9/65</td>
<td>Northeast US</td>
<td>30 million people</td>
</tr>
<tr>
<td>7/13/77</td>
<td>NYC</td>
<td>9 million</td>
</tr>
<tr>
<td>8/24/92</td>
<td>Florida</td>
<td>1 million</td>
</tr>
<tr>
<td>7/2/96</td>
<td>Western US</td>
<td>2 million</td>
</tr>
<tr>
<td>8/10/96</td>
<td>Western US</td>
<td>7.5 million</td>
</tr>
<tr>
<td>Jan 98</td>
<td>Québec</td>
<td>2.3 million</td>
</tr>
<tr>
<td>Feb-Apr 98</td>
<td>Auckland</td>
<td>1.3 million</td>
</tr>
<tr>
<td>8/14/03</td>
<td>Great Lakes</td>
<td>50 million</td>
</tr>
<tr>
<td>8/30/03</td>
<td>London</td>
<td>½ million</td>
</tr>
<tr>
<td>9/18/03</td>
<td>Tidewater US</td>
<td>4 million</td>
</tr>
<tr>
<td>9/23/03</td>
<td>Denmark &amp; Sweden</td>
<td>4 million</td>
</tr>
<tr>
<td>9/28/03</td>
<td>Italy</td>
<td>57 million</td>
</tr>
<tr>
<td>11/7/03</td>
<td>Chile</td>
<td>15 million</td>
</tr>
</tbody>
</table>
The Vast Majority of Blackouts Come from the Distribution system

Distribution failures generally involve only a few people

Large blackouts are caused by failures in the transmission or generation systems.

Really large blackouts stem from cascading failures, where a part of the system fails and leads to other failures spread over a wide area.
Can Blackouts be Prevented?

• The high voltage part of the system contains 157,000 miles, thousands of nodes.
• Natural disasters: Ice storms, hurricanes, earthquakes
  – Québec Ice Storm: 770 transmission towers
  – Hurricane Andrew: 300 towers down
  – Hurricane Isabel: 3 million without power
Common Themes from Blackout Investigations

- Monitoring of the power grid is sparse, and data are not shared among power companies. Inadequate regional and interregional monitoring of the power system.
- Inappropriate standards: vegetation trimmed every 5 years.
- Operators are not routinely trained using realistic simulations.
- Companies have very different equipment, data, and training. Some can quickly interrupt power during an emergency, while others cannot.
- 1982 unimplemented recommendations to display data in a form that makes it easy to see the extent of a problem.
Lessons from Air Traffic Control

• Companies get blamed for systems failures – “operator error”
• Poor monitoring and control systems lead to conservative operations standards that use equipment inefficiently – and still don’t prevent crashes. Comprehensive monitoring is crucial, and so is the ability to interpret the data in real time and take action.
• Individual companies do not have the incentives to fix the problems; voluntary solutions are unlikely to work – regulators must be informed, but rarely have the expertise to arrive at the best solution.
• Investigation and operations should be in separate hands.
• Many of the actions are local or regional, but a national coordination center is required to bring controllers together.
Applying these lessons: Cost-Effective Steps to Prevent Blackouts

The air traffic control system moved beyond a reactions to a crash to a comprehensive plan which included R&D and facilities to handle future issues.

A national grid operations plan is needed, and it should be implemented through an organizational structure which recognizes that human beings make mistakes and that checks and balances are required.
Applying these lessons

Realistic simulator training

– recognize and act upon signs of extreme system stress which may be well outside daily operations experience. “Years of boredom punctuated by moments of stark terror.”

– expose structural deficiencies such as poor lines of authority and insufficient staffing.

– Federal standards for training, licensing, and certification of grid operators and control centers are warranted to ensure that a single weak control center does not bring down a large area.
Applying these lessons

3. Operations control centers must be able to control
   – Load shedding
   – Load reduction

4. Periodic testing of all systems, including load shedding, emergency power, telemetry

5. Regional standards for maintenance (such as tree trimming)
Evolving to an ATC-like system

• If ERO is eventually passed, it will be an interesting social experiment
  – Federally-chartered industry organization enforcing standards it develops with penalties
  – Who will have a veto on the standards?
• Tasks that should be expanded
  – Certification of operators, periodic testing, improved data and control systems, control rooms, & training
Distributed Generation & Security

Large generators & transmission lines are easy targets, difficult to protect.

DG increases reliability by eliminating large, central generations and transmission. Any one distributed generator could be destroyed or fail, but it is all but impossible to destroy all or even most generators.

Hisham Zerriffi has quantified the gain.
A simple "typical" topology has also been modeled for the natural gas system.

Details of the modeling assumptions can be found in Hisham Zerriffi, Hadi Dowlatabadi, and Alex Farrell, "Incorporating Stress in Electric Power System Reliability Models," *Proceedings of the IEEE*, in review for a special issue.
Simulation results for the electric portion of the systems

Results are for the current levels of generation and distribution system reliability.
Increased levels of stress on the system:

NOTE: Gas T&D have much lower failure rates, hence they require orders of magnitude larger increases in failure rates to see comparable loss of energy.
Economic loss from unserved load

NOTE: Loss computed as levelized cost of energy generation and transmission plus $3.83/kWh-unserved.
Increased Vulnerability

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New Vulnerabilities

The Supervisory Control & Data Acquisition system carries messages on the state of the system and conveys orders to operate it. It is highly vulnerable to terrorists.

Electromagnetic pulses could cause major damage.

Increasing reliance on Natural Gas: Pipelines & storage facilities

Infrastructure interdependencies: Gas & electric
A More Solvable Problem

*Survivability* is the ability of a system to fulfill its missions, in a timely manner, in the presence of attacks, failures, or accidents.

Survivable Missions
(supported by Pennsylvania’s DEP)

We need to make vital social services or “missions” robust in the face of power outages.

When the power went out in August 2003, traffic lights stopped working and traffic snarled in all the major cities; water and sewer lines stopped working in cities like Cleveland; people got stranded in the dark in elevators and subway systems.

There is no excuse for any of this to happen.

While we can do things to reduce the probability of cascading blackouts…we cannot eliminate them.
A simple example

When the power goes out, traffic snarls in urban cores, making it impossible for emergency vehicles to get through.

In a “normal” blackout, this is a problem. If a blackout were part of a terrorist attack, it could be very serious.

While old style traffic lights required something like 150 watts, modern traffic lights that use light emitting diodes (LEDs) use less than 15 watts.

LED traffic lights can be kept running for several days on battery back-up.
System interactions

The importance of thinking in terms of making vital missions robust at a system level is provided by the August 2003 blackout.

When the power went out Newark and Kennedy airports were able to quickly restore power for passenger screening and other boarding functions. On the other hand, LaGuardia could not.

Because all three are part of a closely coupled system, air traffic became snarled throughout the east.
A Solvable Problem

• Recognize that blackouts will happen.
• Reduce the social and economic costs by assuring that critical missions continue.
  – Traffic lights
  – Water and sewer pumps
  – Natural gas pressure
  – Emergency service systems
  – Exit from subways and elevators
  – Crucial economic functions
Steps to Implement Survivability

1. Define the missions that must survive.
2. Determine a set of design reference events (extent and duration).
3. Prioritize missions.
4. Which missions are protected already?
5. Which need upgrades?
6. Identify cost-effective technologies (for both private and public goods).
7. Allocate competing resources.
Where Are the Critical Needs?

Backup generators are in place at manufacturing plants, computer installations, TV and radio stations, tall buildings, hospitals, airports …

The private sector (& public agencies that run as if they were private, such as airports) have examined the problem & decided whether to act. The public sector generally has not acted. Budget problems? Too short-term a focus? Politics?

Whatever the cause, public investment is needed
The Other 10%

Terrorism poses different threats: Cyber attack, physical attack on nuclear sites, deliberately trying to blow up gas pipelines, etc.

But: 1. The steps that make a system more reliable generally make it more difficult to inflict damage
2. Greater reliability requires an improved SCADA that should be less vulnerable to attack
3. The social cost of a damaged electricity system is lower if we have DG & survivability
4. The costs of improving reliability & security are lower if the two are done together