Worst Case Electricity Scenarios
The Benefits & Costs of Prevention

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Carnegie Mellon Electricity Industry Center

- One of 22 Sloan Centers of Excellence in different industries
- 17 Faculty & 23 Ph.D. students at Carnegie Mellon University
- Probably the largest effort of its kind in the world focused on interdisciplinary problems of the electricity industry.
- Close cooperation with all stakeholders: Industry, regulators, government agencies, consumers, labor, national laboratories.
- Working with CREATE on Reliability & Security
- Other focal areas:
  - Market Structure & Performance
  - Distributed Energy Resources
  - Advanced Generation & Transmission Technologies
  - Environmental & Sustainability Issues
Who Cares About Electricity?

- An electricity blackout causes us to freeze (sweat) in the dark. We find it difficult to:
  - commute (no traffic signals, no trains)
  - get up & down in buildings (no elevator)
  - work (no light, computers, copiers, faxes)
  - cook (no microwave, refrigerators, appliances, solid state ignition)
  - get entertainment (no TV, radio, VCR)

Almost all modern activities depend on electricity.
This Essential System is Highly Vulnerable

- Central generation creates high value targets
  - & long, vulnerable transmission lines
  - & unique high voltage transformers
  - & vulnerable substations

System is disrupted frequently by natural hazards, human error, & human attack
Long Island Power Authority
Customer Average Interruption Duration

MINUTES

YEAR


68  66  67  64  62  61  67  71  76  76  71  71  68  78  71  71  69
System Average Interruption Duration Index, SAIDI (Exclude Major Events)

Minutes of Sustained Outages Per Customer Per Year

Year

## Some Recent Large Blackouts

<table>
<thead>
<tr>
<th>Date</th>
<th>Region</th>
<th>Affected Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/9/65</td>
<td>Northeast</td>
<td>30 million people</td>
</tr>
<tr>
<td>6/5/67</td>
<td>PA-NJ-MD</td>
<td>4 million</td>
</tr>
<tr>
<td>5/17/77</td>
<td>Miami</td>
<td>1 million</td>
</tr>
<tr>
<td>7/13/77</td>
<td>NYC</td>
<td>9 million</td>
</tr>
<tr>
<td>1/1/81</td>
<td>Idaho-Utah-Wyoming</td>
<td>1.5 million</td>
</tr>
<tr>
<td>3/27/82</td>
<td>West</td>
<td>1 million</td>
</tr>
<tr>
<td>12/14/94</td>
<td>West</td>
<td>2 million</td>
</tr>
<tr>
<td>8/24/92</td>
<td>Florida</td>
<td>1 million</td>
</tr>
<tr>
<td>7/2/96</td>
<td>West</td>
<td>2 million</td>
</tr>
<tr>
<td>8/10/96</td>
<td>West</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>12/8/98</td>
<td>San Francisco</td>
<td>½ million</td>
</tr>
<tr>
<td>8/14/03</td>
<td>Great Lakes-NYC</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</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>Most of Chile</td>
<td>15 million</td>
</tr>
</tbody>
</table>
Valuing Unserved KWh

- Blackouts are costly
- Purchased KWh: 10¢ - Unserved KWh: $2
- Electricity revenue: $250 billion per year
- Consumer surplus from electricity: $2.5-5 trillion per year
- The cost to the US economy from blackouts & defensive measures (backup generation) is billions of dollars per year
Some ‘Worst Case’ Scenarios

1. Ice storm downs transmission & distribution lines & almost 1,000 transmission towers
2. 3 hurricanes hit same location in 6 weeks
3. Earthquake collapses bridges & highways, taking out electrical system
4. Reactive power shortage leads to a cascade that blacks out 50 million people
5. Large hurricane floods New Orleans for weeks
‘Worst Case’ Scenarios?

1. Ice Storm: Quebec & NY in 1998
2. 3 Hurricanes: Florida in 2004
3. Earthquake: Bay area, California in 1989
4. Reactive power: NE in 2003
5. Hurricane Ivan: Almost occurred in 2004

Since these happened recently, a 500 year worst case would be much, much worse
Causes of All Outages

- Equipment Underground (UG): 22%
- Equipment Overhead (OH): 12%
- Weather: 16%
- Tree Related: 16%
- Public: 8%
- Substation: 6%
- Animal: 7%
- Transmission: 4%
- Utility Error: 2%
- Other: 7%

Illinois, 2000
Failure Statistics 1984-2000

- 533 transmission or generation events
- 324 had non trivial power loss
- 46 of these (3 per year) were >1000 MW
Causes of Major Disturbances

- **Equipment Failure**: (165) 31%
- **Weather & Fire**: (208) 40%
- **Insufficient Generation**: (81) 15%
- **Human Error**: (59) 11%
- **Sabotage**: (16) 3%

Source: Analysis of NERC DAWG data 1984-2000 by Jay Apt
Are Blackouts Getting More Frequent?

Number of Blackouts affecting 1,000,000 or more customers

Source: Jay Apt analysis of NERC Distribution Analysis Working Group (DAWG) Database
Are We Adequately Backed Up?

• In Pittsburgh, 2 of 5 police are backed up
  – $48,000 total capital cost to back up all zones
• 15% of Pittsburgh customers would lose water with a 1-day power outage, 50% after 3 days.
• Detroit, Cleveland, & New York dumped untreated sewage into water bodies on 8-14.
• Many hospitals, factories, stores, etc. that thought they were backed up lost power
Other Infrastructure

- Land-line telephones have robust backups (& were functional on 8/14)
- BUT: handsets & new phone systems need electric power
- Cellular tower transmitters lose battery power in 6 hours
- Most natural gas pipelines are self-powered
- Garbage services typically do not have emergency diesel contracts
Human Attack

- Human attack could cause a blackout by taking out transmission lines during peak demand. This could be done by dynamiting transmission towers or destroying high voltage transformers.

- Worse case: At a time of peak demand, 24 terrorists drive vans filled with explosives into New York City, attacking 24 tall buildings at 4:30 PM after timed explosives take down 4 major transmission lines. The resulting blackout darkens traffic signals causing gridlocked streets. Police & firemen cannot get trucks to damaged, burning buildings. Panic ensues as commuters try to get home amidst frozen elevators, subways, & trains, as well as gridlocked streets.
Human Attack

• Other worse case: Terrorists destroy high voltage transformers on the largest transmission lines serving New York, Boston, Philadelphia, Chicago, Los Angeles, etc. The cities lose 30-70% of their electricity supply for more than one-year.
How Much Reliability Do We Want?

• Terrorists, natural hazards, & error can all cause blackouts in similar ways.
• Many (but not all) measures to protect against one problem offer protection against all.
• US electricity system is less reliable than UK, Japan, etc.
• We choose not to spend more to increase reliability
• Economic loss for shutdown is $112 per person per day
• Additional losses from injury & death, crime, & delay
• E.g., 8-14-03 => 50 million people x $112 = $5.6 billion
• Next graph shows whether to invest in backup, given capital cost & loss if electricity fails.
Example analysis for backup systems with 12 year depreciation at 7% discount rate & annual O&M cost equal to 2.5% of capital cost.
Creating Greater Resilience: Lessen Damage from Nat Haz, Errors, & Attacks

1. Improve operator training & communication
2. Multiple transmission lines to deliver electricity
3. Diversified fuel supply
4. On-site fuel storage
5. Diversified generation technology
6. Decentralized generation
7. Backup generators
8. Ability to shed individual loads automatically
9. Improved, secure information & control technologies
10. Standardize transmission voltages & inventory high voltage transformers
1. Improve Operator Training & Communication

• Regular training on simulators
• Dedicated lines to critical operators & ISO
• Real time displays about conditions throughout the system with time stamp on when data were gathered
2. Multiple Transmission Lines to Deliver Electricity

- Long transmission lines are impossible to protect & highly vulnerable
- Need multiple, redundant lines in different corridors
- Only certain solution is distributed generation
3. Diversified Fuel Supply

Electricity generation has been curtailed or threatened by:

- 1975 OPEC oil embargo
- Threatened shut-down of nuclear plants after Three Mile Island
- Scarcity & high price of natural gas since 2000
- Droughts, which curtail hydro-electric generation
- Limits on carbon-dioxide & other greenhouse gases threaten fossil fuel generation

It is impossible to predict droughts or other untoward circumstances. Best to have a diversified portfolio of fuels.
4. On-Site Fuel Storage

• Fuel deliveries are vulnerable: Natural hazards, accidents, human error, markets, terrorists
• Nuclear & coal best, natural gas & wind worst
• Wind requires backup, but natural gas usually is not backed up. But if there is no local storage, a break in delivery could stop generation & cause a blackout
• Trend toward less coal storage is unfortunate
5. Diversified Generation Technology

• As with fuels, a focus on one generation technology can cause problems:
  – Pulverized coal was retrofitted with technologies to control SOx, NOx, particles, mercury, …
  – Various problems have shut one type of nuclear reactor for repair and retrofit
  – Early model wind turbines had maintenance problems & chopped up birds
  – Almost all new generation capacity built in the 1990s as NGCC, but then the price of gas rose
6. Decentralized Generation

- Eliminating “power parks” removes attractive targets
- Also reduces or eliminates transmission lines
- No spillover from other generating units (TMI-2 put TMI-1 out of operation for years)
- Moving generation closer to customer lowers exposure to natural hazards & terrorists
- Inherently greater reliability
7. Backup Generators

• Achieving perfect reliability is impossible
• Outage frequency is high enough so that high value customers find backup generation has benefits greater than costs
• On 8-14 many hospitals, factories, stores, etc. with backup generators found that they did not work; for reliability, these generators must be tested monthly under full load
• There must be sufficient onsite fuel storage to last until external supply is restored or fuel can be replenished
8. Ability to Shed Individual Loads Automatically

• At 10¢ per KWh, most electricity goes to low value uses, e.g., pool pumps, dishwashers, etc.
• If demand had to be curtailed for a few hours or even a day, there would be little inconvenience to cutting demand by 50, 70, or even 90%
• Today, shedding demand means shutting down a substation & all the customers it serves
• The ability to shed individual loads automatically would increase reliability & lower cost
9. Improved, Secure Information & Control Systems

- Many utilities have moved from dedicated SCADA systems to internet or telephone based systems
- These systems are vulnerable to disgruntled employees or hackers
- Controllers need better real time information on the state of each generator, transmission line, & substation demand
10. Standardize Transmission Voltages & Inventory High Voltage Transformers

- Many utilities had unique voltages & wire specifications leading to additional expense and making it difficult to have spare transformers in inventory.
- Standardizing transmission voltages would lower costs & allow inventories of spare transformers to lessen the outage time if a transformer is destroyed.
Conclusion

• The US electricity system currently experiences many disruptions due to natural hazards & human error. Large, costly blackouts occur frequently.

• It is highly vulnerable to human attack. A worst case scenario would be highly destructive.

• Many investments would simultaneously improve reliability & reduce vulnerability or the amount of damage from terrorist attack

• Evaluating the reliability & security benefits together would justify many new investments