Joint U.S.-Canada Power System Outage Investigation

Interim Report
Causes of the August 14th Blackout in the United States and Canada

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Overview

- The report
- What caused the blackout?
- Reliability management
- What didn't cause the blackout?
- How do we know this?
- Key events in the blackout
- Why did the cascade spread?
- Why did the cascade stop where it did?
- Next steps

U.S.-Canada Interim Report

- Released November 19, 2003
- Result of an exhaustive bi-national investigation
  - Working groups on electric system, nuclear plant performance and security
  - Hundreds of professionals on investigation teams performed extensive analysis
- Interim report produced by the teams and accepted by the bi-national Task Force

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Conclusions of the Interim Report

- What caused the blackout
  - Inadequate situational awareness by FirstEnergy
  - Inadequate tree-trimming by FirstEnergy
  - Inadequate diagnostic support by reliability coordinators serving the Midwest
- Explanation of the cascade and major events
- Nuclear plants performed well
- No malicious cyber attack caused blackout

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What caused the blackout (1)

- FirstEnergy lost its system condition alarm system around 2:14pm, so its operators couldn't tell later on that system conditions were degrading.
- FE lost many capabilities of its Energy Management System from the problems that caused its alarm failure – but operators didn't realize it had failed
- After 3:05pm, FE lost three 345 kV lines due to contacts with overgrown trees, but didn't know the lines had gone out of service.

What caused the blackout (2)

- As each FE line failed, it increased the loading on other lines and drove them closer to failing. FE lost 16 138kV lines between 3:39 and 4:06pm, but remained unaware of any problem until 3:42pm.
- FE took no emergency action to stabilize the transmission system or to inform its neighbors of its problems.
- The loss of FE's Sammis-Star 345 kV line at 4:05:57pm was the start of the cascade beyond Ohio.

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What caused the blackout (3)

- MISO (FE's reliability coordinator) had an unrelated software problem and for much of the afternoon was unable to tell that FE's lines were becoming overloaded and insecure.
- AEP saw signs of FE's problems and tried to alert FE, but was repeatedly rebuffed.
- PJM saw the growing problem, but did not have joint procedures in place with MISO to deal with the problem quickly and effectively.

What caused the blackout (4)

1) FirstEnergy didn't properly understand the condition of its system, which degraded as the afternoon progressed.

- FE didn't ensure the security of its transmission system because it didn't use an effective contingency analysis tool routinely.
- FE lost its system monitoring alarms and lacked procedures to identify that failure.
- After efforts to fix that loss, FE didn't check to see if the repairs had worked.
- FE didn't have additional monitoring tools to help operators understand system conditions after their main monitoring and alarm tools failed.

What caused the blackout (5)

2) FE failed to adequately trim trees in its transmission rights-of-way.

- Overgrown trees under FE transmission lines caused the first three FE 345 kV line failures.
- These tree/line contacts were not accidents or coincidences
- Trees found in FE rights-of-way are not a new problem
  - One tree over 42’ tall; one 14 years old; another 14” in diameter
  - Extensive evidence of long-standing tree-line contacts

What caused the blackout (6)

3) Reliability Coordinators did not provide adequate diagnostic support to compensate for FE's failures.

- MISO's state estimator failed due to a data error.
- MISO's flowgate monitoring tool didn't have real-time line information to detect growing overloads.
- MISO operators couldn't easily link breaker status to line status to understand changing conditions.
- PJM and MISO lacked joint procedures to coordinate problems affecting their common boundaries.

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Reliability management (1)

Fundamental rule of grid operations – deal with the grid in front of you and keep it secure. HOW?

1) Balance supply and demand
2) Balance reactive power supply and demand to maintain voltages
3) Monitor flows to prevent overloads and line overheating
4) Keep the system stable

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Reliability management (2)

5) Keep the system reliable, even if or after it loses a key facility

6) Plan, design and maintain the system to operate reliably

7) Prepare for emergencies
   - Training
   - Procedures and plans
   - Back-up facilities and tools
   - Communications

8) The control area is responsible for its system

What didn't cause the blackout (1)

1) High power flow patterns across Ohio
   - Flows were high but normal
   - FE could limit imports if they became excessive

2) System frequency variations
   - Frequency was acceptable

3) Low voltages on 8/14 and earlier
   - FE voltages were above 98% through 8/13
   - FE voltages held above 95% before 15:05 on 8/14

What didn't cause the blackout (2)

4) Independent power producers and reactive power

- IPPs produced reactive power as required in their contracts
- Control area operators and reliability coordinators can order higher reactive power production from IPPs but didn't on 8/14
- Reactive power must be locally generated and there are few IPPs that are electrically significant to the FE area in Ohio

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What didn't cause the blackout (3)

5) Unanticipated availability or absence of new or out of service generation and transmission

- All of the plants and lines known to be in and out of service on 8/14 were in the MISO day-ahead and morning-of schedule analyses, which indicated the system could be securely operated

6) Peak temperatures or loads in the Midwest and Canada

- Conditions were normal for August

7) Master Blaster computer virus or malicious cyber attack

How do we know this?

- The Task Force investigation team has over two hundred experts from the US and Canada government agencies, national laboratories, academics, industry, and consultants
- Extensive interviews, data collection, field visits, computer modeling, and fact-checking of all leads and issues
- Logical, systematic analysis of all possibilities and hypotheses to verify root causes and eliminate false explanations

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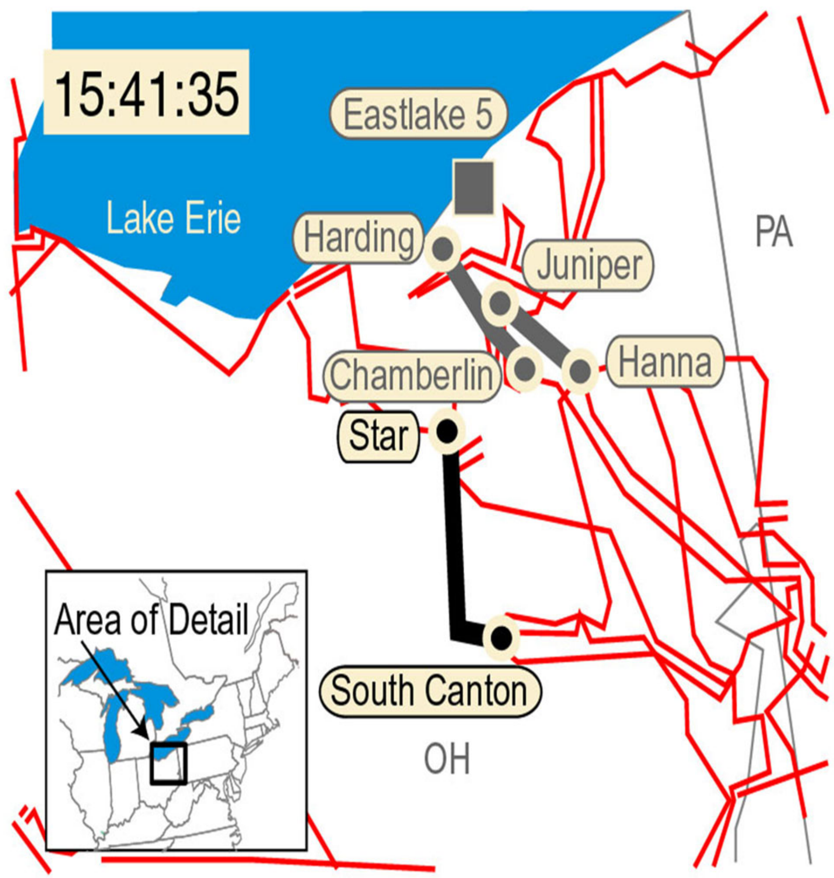
What happened on August 14

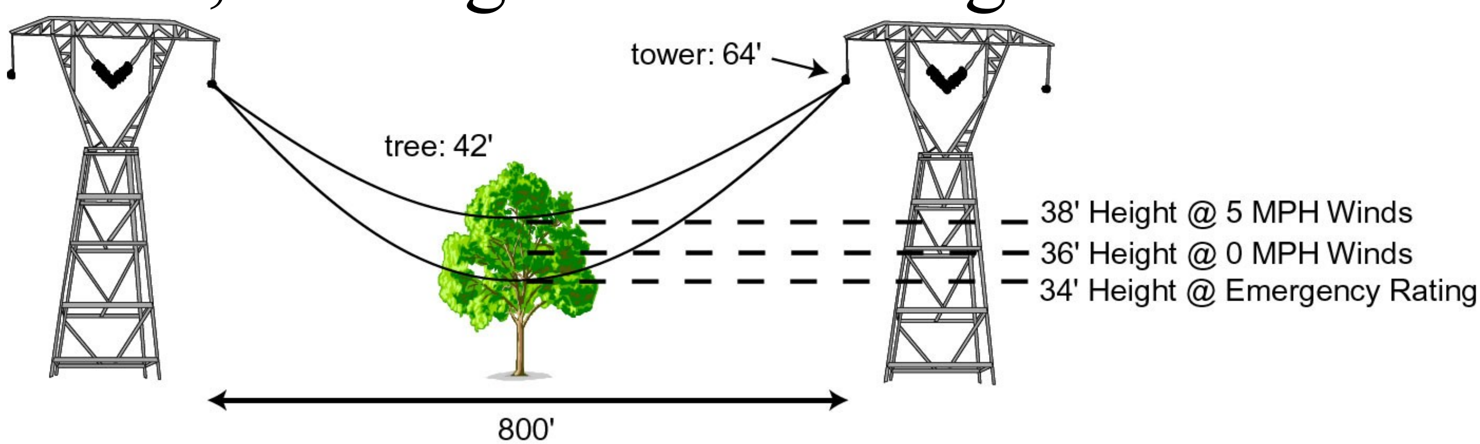
- At 1:31 pm, FirstEnergy lost the Eastlake 5 power plant, an important source of reactive power for the Cleveland-Akron area
- Starting at 3:05 pm EDT, three 345 kV lines in FE's system failed – within normal operating load limits -- due to contacts with overgrown trees



What happened (2) -- Ohio

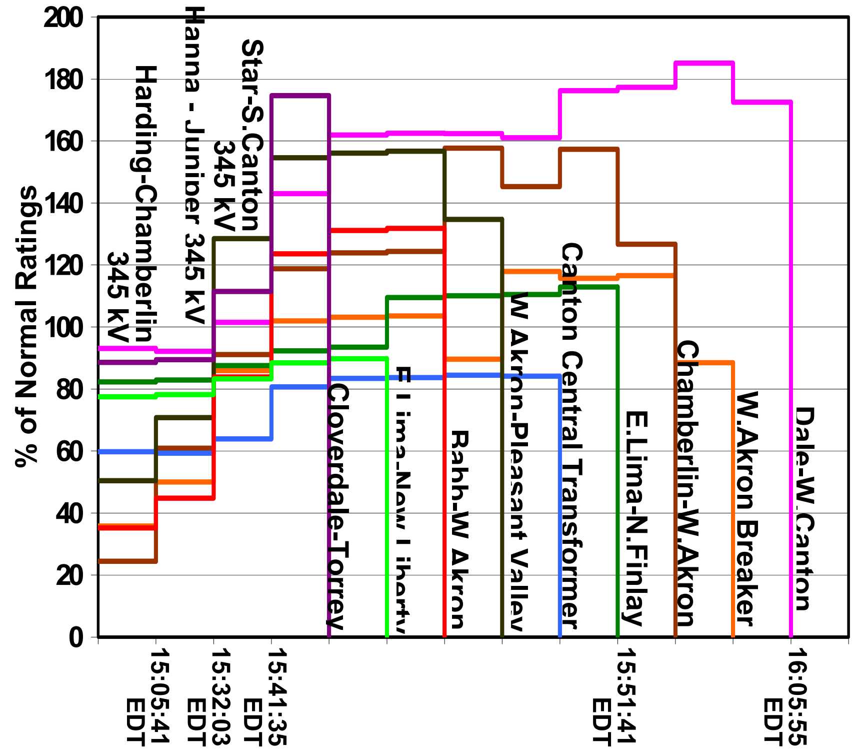
Why did so many trees contact power lines?

- The trees were overgrown because rights-of-way hadn't been properly maintained
- Lines sag lower in summer with heat and low winds, and sag more with higher current



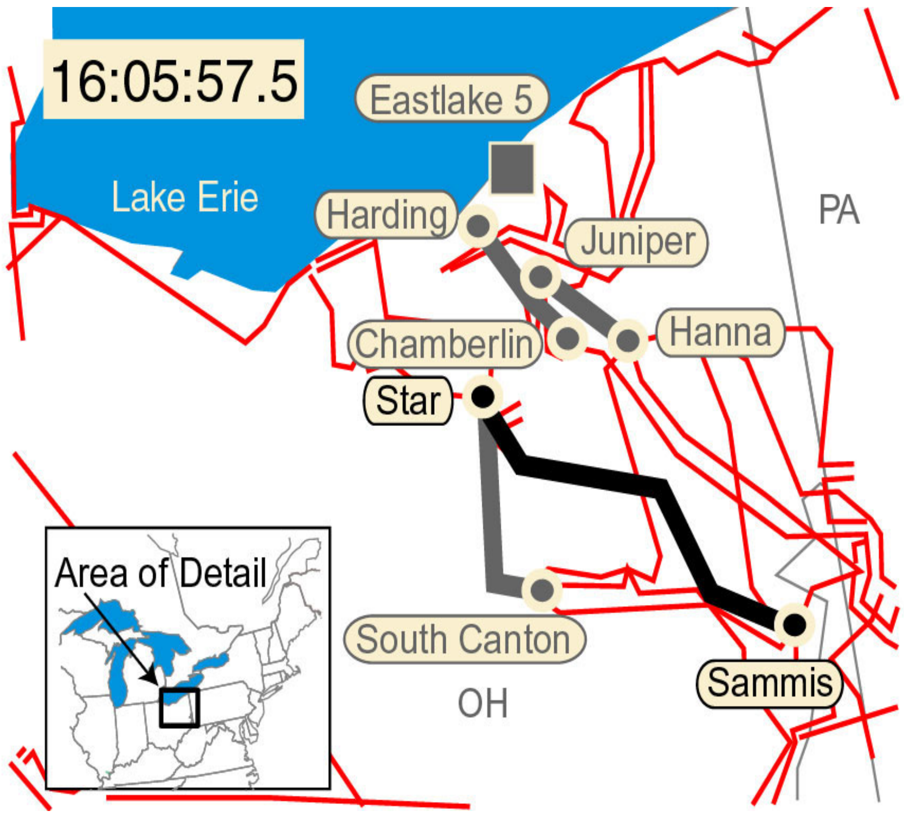
What happened (3) -- Ohio

After the 345 kV lines were lost, at 3:39 pm FE's 138 kV lines around Akron began to overload and fail; 16 overloaded and tripped out of service



What happened (4) -- Ohio

At 4:05 pm, after FirstEnergy's Sammis-Star 345 kV line failed due to severe overload.



What happened (5) -- cascade

- Before the loss of Sammis-Star, the blackout was only a local problem in Ohio
- The local problem became a regional problem because FE did not act to contain it nor to inform its neighbors and MISO about the problem
- After Sammis-Star fell at 4:05:57, northern Ohio's load was shut off from its usual supply sources to the south and east, and the resulting overloads on the broader grid began an unstoppable cascade that flashed a surge of power across the northeast, with many lines overloading and tripping out of service.

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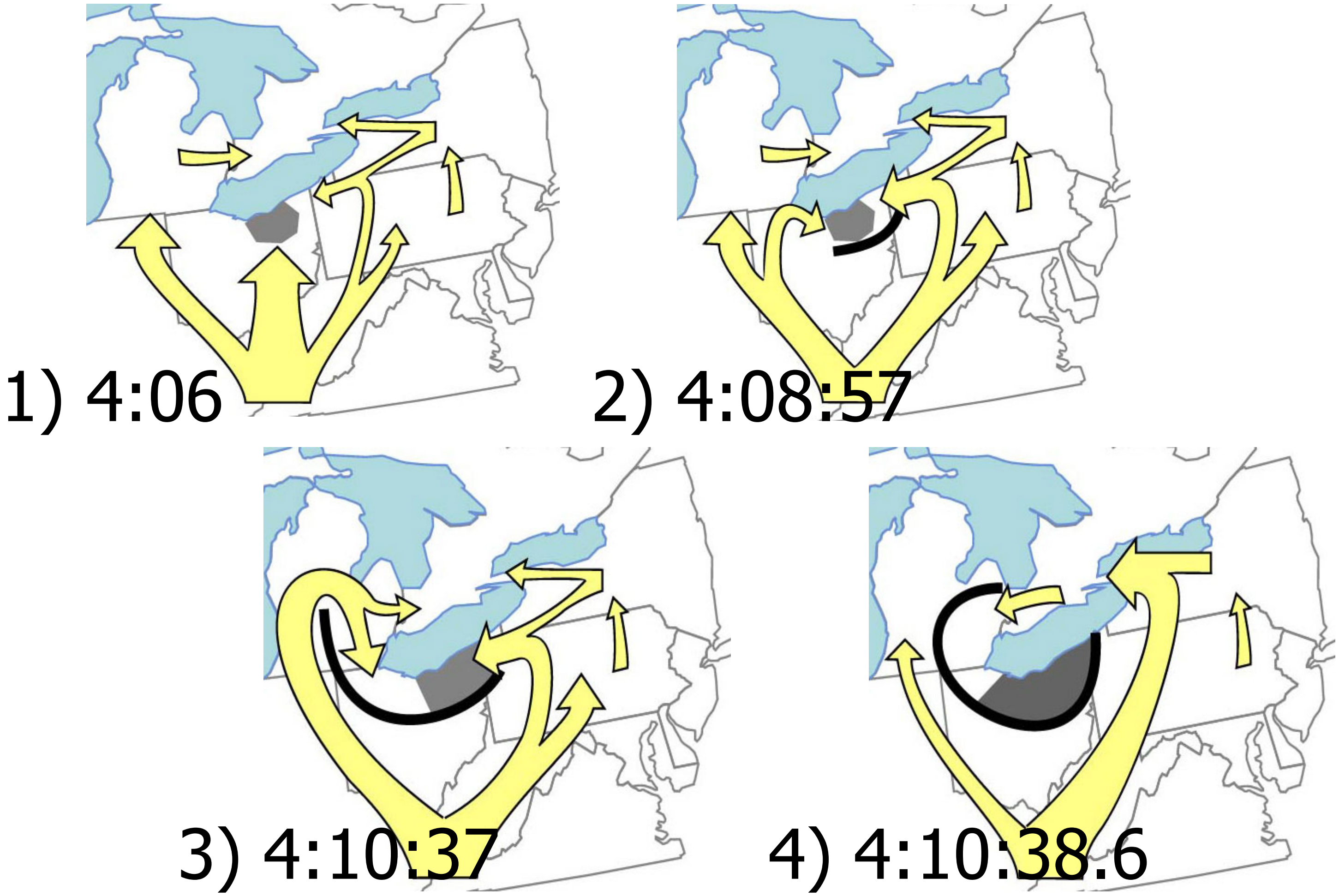
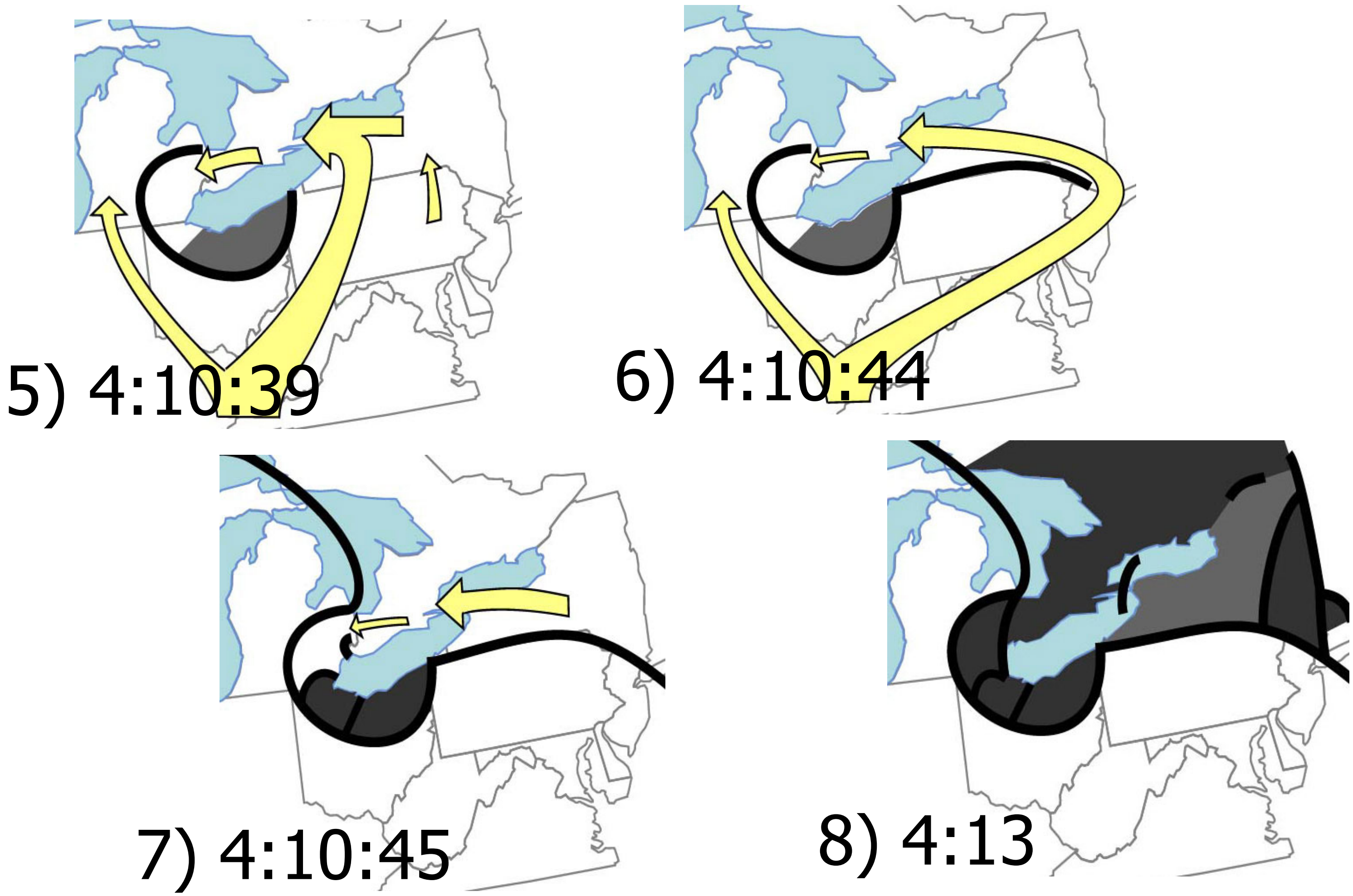
What happened (6) -- cascade

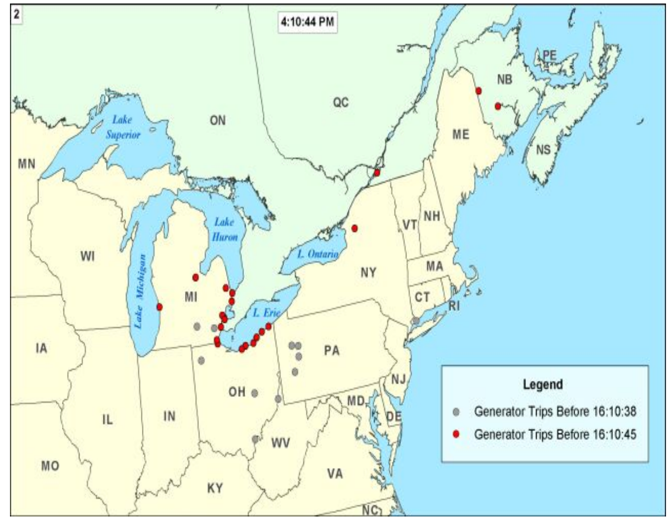


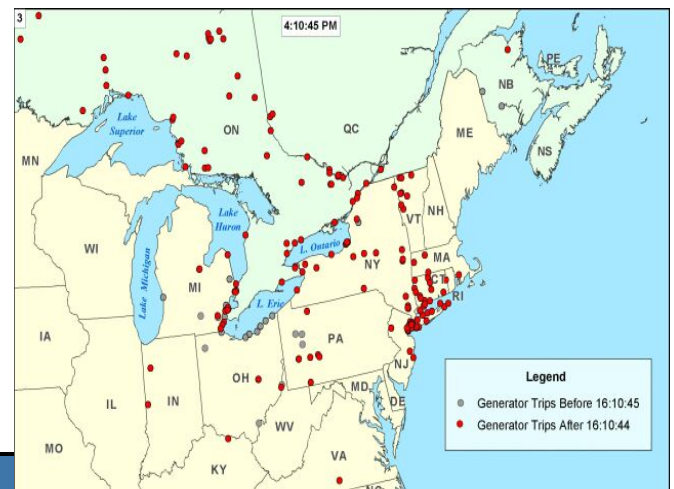
What happened (7) -- cascade



Power plants affected

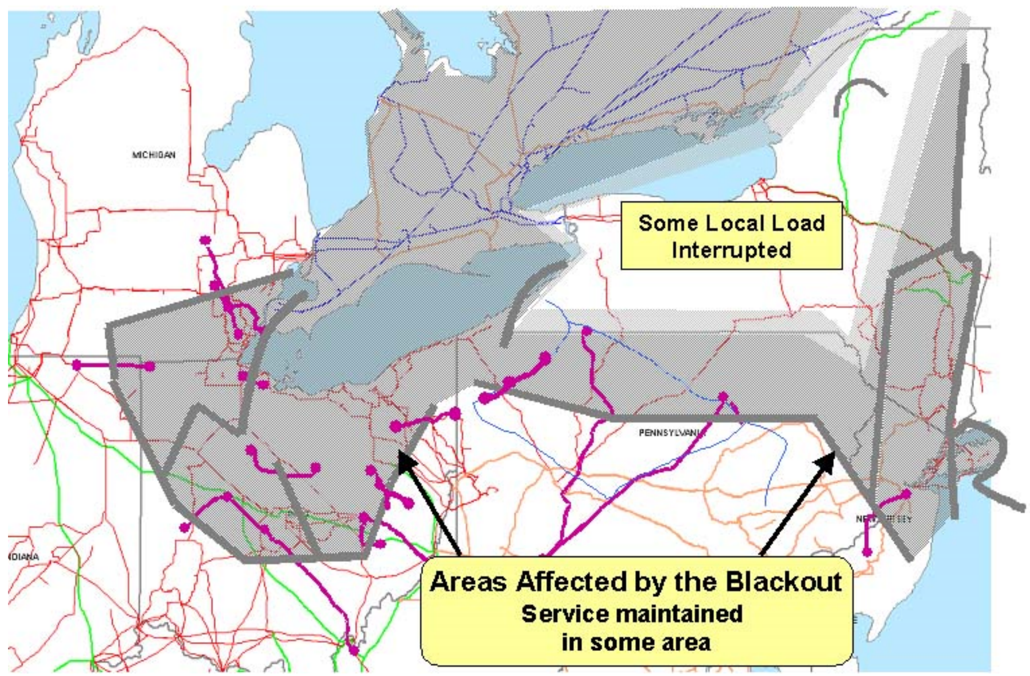
- The blackout shut down 263 power plants (531 units) in the US and Canada, most from the cascade after 4:10:44 pm – but none suffered significant damage





Affected areas

When the cascade was over at 4:13pm, over 50 million people in the northeast US and the province of Ontario were out of power.



Why the cascade spread

- Sequential tripping of transmission lines and generators in a widening geographic area, driven by power swings and voltage fluctuations.
- The result of automatic equipment operations (primarily relays and circuit breakers) and system design

Why the cascade stopped

- Early line trips separated and protected areas from the cascade (southern Ohio).
- Higher voltage lines are better able to absorb voltage and current swings, so helped to buffer against the cascade (AEP, Pennsylvania).
- Areas with high voltage profiles and good reactive power margins weren’t swamped by the sudden voltage and power drain (PJM and New England).
- Areas with good internal balances of generation to load could reach internal equilibrium and island without collapsing (upstate New York and parts of Ontario's Niagara and Cornwall areas).

Next steps

- Phase 1 investigation continues – more data analysis and modeling of the cascade
- Phase 2 – develop recommendations
  - Public consultations in Cleveland, New York, Toronto to receive feedback on Interim Report and recommendations on how to prevent the next blackout
  - Letters and comments welcome to US DOE and Natural Resources Canada websites
  - Final report released in early 2004.

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