Resilient Smart Electric Systems

PSERC Summer School
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Different phases of resilience

- The vertical axis shows the performance of the system such as:
  - Availability of critical facilities,
  - The number of people served,
  - The amount of flow or services delivered,
  - The level of economic activity
General sequence of events leading to blackouts

To achieve a resilient electric systems:
It is crucial to understand the sequence of events during outages.

Overview of prior blackouts

- November 9, 1965 northeast U.S./Canada blackout
- July 2, 1996 western U.S. blackout
- March 11, 1999 Brazil blackout
- September 23, 2003 in Southern Sweden and Eastern Denmark
- August 14, 2003 in North America
- September 28, 2003 Italian Blackout
- September 8, 2011 blackout in the Southwest USA
Overview of Historic Blackouts:
August 14, 2003 North America
The region affected by the U.S.-Canadian blackout of 14 August 2003.

Based on the North American Electric Reliability Council (NERC) investigation, prior to the ensuing events that led to the blackout, the system was being operated in compliance with NERC operating policies.

Apparent reactive power supply problems in the states of Indiana and Ohio prior to noon. The Midcontinent ISO (MISO) state estimator (SE) and real-time contingency analysis (RTCA) software were inoperative (software problems) for most of the afternoon. This prevented MISO from performing proper “early warning” assessments of the system.

Computer software failures occurred on the FirstEnergy (FE) energy management system (EMS) software starting at 2:14 p.m. This prevented FE from having adequate knowledge of the events taking place on its own system until approximately 3:45 p.m. This contributed to inadequate situational awareness at FE.
<table>
<thead>
<tr>
<th>Time (pm)</th>
<th>State</th>
<th>Events</th>
<th>Impact</th>
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</thead>
<tbody>
<tr>
<td>12:05-1:31</td>
<td>Ohio</td>
<td>Eastlake generation unit trip</td>
<td>Loss of Generation capacity</td>
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<tr>
<td>2:02</td>
<td>Ohio</td>
<td>Stuart-Atlanta line disconnects 345-kV</td>
<td>Loss of line</td>
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<tr>
<td>3:05-3:31</td>
<td>Ohio</td>
<td>Three more 345-kV lines disconnect</td>
<td>Loss of lines</td>
</tr>
<tr>
<td>3:45-4:08</td>
<td>Ohio</td>
<td>Two more 345-kV and 138-kV lines disconnect</td>
<td>Loss of lines</td>
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<tr>
<td>4:08-4:10</td>
<td>Michigan</td>
<td>Kinder Morgan generation trips 200 MW</td>
<td>Loss of 200 MW generation capacity</td>
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<tr>
<td>4:10</td>
<td></td>
<td>Twenty generators along Lake Erie shut down</td>
<td>Loss of 2,174 MW generation capacity</td>
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<tr>
<td>4:10</td>
<td></td>
<td>Four transmission lines disconnect between Pennsylvania and New York</td>
<td>Loss of lines</td>
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<tr>
<td>4:10</td>
<td></td>
<td>New York-New England lines disconnect (New England islands, stays</td>
<td>Loss of lines</td>
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<td></td>
<td></td>
<td>operational)</td>
<td></td>
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<tr>
<td>4:11</td>
<td></td>
<td>Ontario system separates from New York west of Niagara Falls</td>
<td></td>
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<tr>
<td>4:12</td>
<td></td>
<td>Remaining lines between Michigan and Ontario separate</td>
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<td>4:13</td>
<td></td>
<td>Cascading sequence essentially complete</td>
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Timeline: 2003 Northeast Blackouts

**Phase 1:** A normal afternoon degrades 12:15-14:14
- 13:01: Eastlake 5 trips
- 13:31: Stuart-Atlanta 345 kV fails (tree)

**Phase 2:** FE's computer failures 14:14-15:59
- 14:02: Star-S Canton 345 kV trips & recloses (tree)
- 14:27: Harding-Chamberlin 345 kV fails (tree)

**Phase 3:** FE 345 kV line failures 15:05-15:57
- 15:05: Hanna-Juniper 345 kV fails (tree)
- 15:32: First FE 138 kV line fails
- 15:41: Star-S Canton 345 kV fails (tree)

**Phase 4:** Collapse of 138 kV system 15:39-16:08
- 15:42: 15 more FE 138 kV lines fail
- 15:46-15:59: Sammis-Star 345 kV line fails

**Grid Events**
- 12:15: MISO SE problems begin
- 14:14: FE EMS alarms fail
- 14:41: FE primary EMS server fails
- 15:08: FE primary EMS server restarts
- 15:32: First FE 138 kV line fails
- 15:46-15:59: FE IT reboots H4, H1

**Computer Events**
- 13:31: Stuart-Atlanta 345 kV trip confuses MISO SE
- 14:02: FE loses half its remote consoles
- 14:54: FE back-up EMS server fails
- 15:46: FE says system could fail
- 15:46: PJM calls FE re: Star-South Canton

**Human Events**
- 14:32: AEP calls FE re: Star-S Canton trip
- 14:32: FE EMS doesn't update
- 15:19: AEP again calls FE re: Star-S Canton
- 15:35: AEP & PJM work TLR
- 15:36: MISO calls FE re: Star-Juniper
- 15:42: FE operator tells IT alarms cut
- 15:45: FE says system could fail
- 15:46: FE manning substations
- 15:48: PJM calls FE re: line outages

Eastlake Unit 5 and several other generators in FE’s Northern Ohio service area were generating high levels of reactive power, and the reactive power demand from these generators continued to increase as the day progressed.

Such high reactive power loading of generators can be a concern and may lead to control and protection problems.

The Eastlake Unit 5 voltage regulator tripped to manual due to overexcitation. As the operator attempted to restore automatic voltage control, the generator tripped.

Timeline: 2003 Northeast Blackouts

Chamberlin-Harding 345-kV line tripped due to tree contact; the line was only loaded to 44% of summer normal/emergency rating.

The Hanna-Juniper 345-kV line loaded to 88% of its summer emergency rating and tripped due to tree contact.
This cascading loss of lines continued while little action was being taken to shed load or readjust the system since during this period, due to EMS failures at FE and MISO control centers, there was little awareness of the events transpiring.
The critical event leading to widespread cascading in Ohio and beyond was the tripping of the Sammis-Star 345-kV line at 4:05:57 p.m. The line tripped by the Sammis End Zone 3 relay operating on real and reactive current overload and depressed voltage. Tripping of many additional lines in Ohio and Michigan by Zone 3 relays, or Zone 2 relays set similar to Zone 3 relays, followed. Prior to the Sammis–Star tripping, the blackout could have been prevented by load shedding in northeast Ohio.
• At approximately 4:10 p.m., due to the cascading loss of major tie-lines in Ohio and Michigan, the power transfer between the United States and Canada on the Michigan border shifted.

• That is, power started flowing counterclockwise from Pennsylvania through New York and Ontario and finally into Michigan and Ohio. This huge (3,700 MW) reverse power flow was intended for serving load in the Michigan and Ohio system, which was at this stage severed from all other systems except Ontario.

• At this point, voltage collapsed due to extremely heavily loaded transmission, and a cascading outage of several hundred lines and generators ensued, culminating in a blackout of the entire region.
Discussion

• What were the underlying issues?

• No prior work could successfully simulate the 2003 Northeast blackout. Why?

• How can we make the system resilient to avoid these events?
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- Improve situational awareness:
  - Advance measurement technologies
  - EMS
  - Faster computers: hardware and software
  - Controlled islanding
  - Energize the islanding using distributed resources
  - Demand side participation
  - Advance software tools
  - Operation condition based remedial action schemes
  - Equip protection systems to communication network
  - Leverage data analytics to advance situational awareness.