Overview

- Overview of power system and reliability
- Pre-outage conditions on August 14
- Trigger events and start of cascade
- Wide area cascade
- Root causes
- Canada Restoration Activities

Reliability Overview

- Balance generation and demand
- Balance reactive power supply and demand
- Monitor flows and observe thermal limits
- Observe power and voltage stability limits
- Operate for unplanned contingencies
- Plan, design and maintain a reliable system
- Prepare for emergencies

Reliably operate the system you have!
Footprints of Reliability Coordinators in Midwest

Blackout Statistics
- 60 Million people in 8 states and 2 provinces
- Almost 62,000 Mw of load
  - PJM Interconnection - 4,000 Mw
  - Midwest ISO - 18,500 Mw
  - Hydro Quebec - 100 Mw
  - Ontario IMO - 21,000 Mw
  - ISO New England - 2,500 Mw
  - New York ISO - 24,400 Mw
- 34,000 Miles of Transmission
- 290+ Generating Units

August 14 Conditions Prior to Blackout
- Planned outages:
  - Cook 2, Davis Besse nuclear plants
  - East Lake 4, and Monroe 1
- Transfers high to northeast U.S. + Ontario
  - Not unusually so and not above transfer limits
- Critical voltage day
  - Voltages within limits
  - Operators taking action to boost voltages
- Frequency
  - Typical for a summer day
- System was within limits prior to 15:05, on both actual and contingency basis

Warm But Not Unusual for August

August 14 Imports to Northeast-Central Compared to 6/1 to 8/13/2003

Pre-Blackout Loads, Generation and Interchange
Voltages Prior to 15:05 EDT August 14

Frequency Typical for Summer Day

Blackout Sequence of Events

Characteristics of a Disturbance
- Frequency excursions
  - Generation > Load = Frequency Rise
  - Generation < Load = Frequency Decline
- Voltage Excursions (in the blackout region)
  - Declines, leading to voltage collapse in some areas
    - Insufficient reactive power (VARs) is the principal reason for voltage decline and collapse
  - Overvoltages after load trips

Frequency in Chattanooga, TN

Frequency excursions in the Midwest
“Softswitching Technologies – I-grid Monitors”

Red dots indicate measured low voltage events. No monitors shown in Canada.

Time: 8/14/03 4:57 PM EDT

“Softswitching Technologies – I-grid Monitors”

Within 42 seconds voltage problems appear in New York.

Time: 8/14/03 4:40:30 PM EDT

“Softswitching Technologies – I-grid Monitors”

Within the next 19 seconds voltage problems are widespread.

Time: 8/14/03 4:10:58 PM EDT

Unusual Voltage Problems

“Hours before the Aug. 14 blackout, operators at FirstEnergy, the utility that serves much of northeastern Ohio, noticed a peculiar thing: voltage across their system was below normal, a sign of insufficient reactive power. Even though FirstEnergy was importing thousands of megawatts from southern Ohio, “we were exporting VAR’s outside the FirstEnergy system the whole day,” said Charles E. Jones, a senior vice president. ‘That’s not normal.’”
Blackout was NOT Caused by

- Heavy wide-area transfers
- Low voltages, voltage collapse
- Lack of IPP voltage/reactive support
- Frequency anomalies
- Cinergy outages starting at 12:08
- East Lake 5 trip at 13:31
  - Contributing factor to later events, but not by itself causal to the blackout
- DPL Stuart-Atlanta trip at 14:02
  - Contributing factor to loss of MISO real-time monitoring, but not electrically significant
System Operator Comments

- Phone call from Cinergy operator to MISO Operator at 2:36pm:
  - "I hate to worry you, but I think we're a trip away from ... setting a little history."

MISO State Estimator and Reliability Analysis

- MISO state estimator and contingency analysis ineffective from 12:37 to 16:04
  - State estimator not solving due to missing information on lines out in Cinergy then DPL
  - Human error in not resetting SE automatic trigger
  - Using Flowgate Monitoring tool to monitor conditions on previously identified critical flowgates

FirstEnergy Computer Failures

- 14:14 Alarm processing subsystem fails and operators are not aware
  - No further status changes or alarms to FE operators
- 14:20 Several remote consoles fail
- 14:41 EMS server hosting alarm processor and other functions fails to backup
- 14:54 Backup server fails
  - EMS continues to function but with very degraded performance (5s refresh)
  - FE system data passed normally to others: MISO and AEP
  - AGC function degraded and strip charts flat-lined
- 15:08 IT warm reboot of EMS appears to work but alarm process not tested and still in failed condition
- No contingency analysis of events during the day including loss of East Lake 5 and subsequent line trips

Phone Calls between MISO and First Energy

- 3:36pm - MISO asks “… what is going on over there?”
- First Energy says they are unsure.
- MISO replies, “I wonder what is going on here. Something strange is happening.”

Phone Calls to FirstEnergy

- FE received calls from MISO, AEP, and PJM indicating problems on the FE system but did not recognize evolving emergency
  - 14:32 AEP calls regarding trip and reclose of Star-S. Canton
  - 15:19 AEP calls again confirming Star-S. Canton trip and reclose
  - 15:35 Calls received about “spikes” seen on system
  - 15:36 MISO calls FE regarding contingency overload on Star-Juniper for loss of Hanna-Juniper
  - 15:45 FE tree trimming crew calls in regarding Hanna-Juniper flashover to a tree
  - PJM called MISO at 15:48 and FE at 15:56 regarding overloads on FE system

Phone Calls to FirstEnergy

- First Energy told MISO that the voltage on a major line was dangerously low. “Do you have any idea what is going on?”
- MISO replied that the Hanna-Juniper line was out, adding “I am wondering if it is still out.”
- “We have no clue” First Energy replied. “Our computer is giving us fits too. We don’t even know the status of some of the stuff around us.”
- MISO comments: “I can’t get the big picture of what’s going on. Strange things are all happening at the same time.”
“You’re On the Air!”

August 14th transcript of Midwest ISO control center from 1:00 to 5:00 pm Eastern Time.

Thank you for joining us this morning to discuss the current status of the Midwest electrical grid. As you know, we have been experiencing some challenges due to the ongoing drought and the recent heatwaves across the region. Today, we will be focusing on the efforts being made to ensure a reliable and sustainable power supply.

Chamberlin-Harding Indication of Ground Fault Due to Tree Contact as Measured by DFR at Juniper

Blackout Sequence – Phase 2

“Your’s On The Air!”

1. Hi, Tim, 3:05:41
   Midwest Electric Co./Blaine: Hi, Tim. This is Blaine at 3:05.

2. Hi, Blaine. All right.
   MidWest Electric Co./Blaine: Rep, we're having problems with our DFRs, and I guess we were wondering if you went monitoring if you were monitoring problems?

3. MN/Blaine: Rep, we have a problem, you know, I haven't personally -- hang on. Let me transfer you over to the other guys and see what they say.


5. MN/Blaine: Keep on.
Hanna Juniper Confirmed as Tree Contact at Less than Emergency Ratings of Line

“LEGAL” RESTRICTIONS ON VEGETATION MANAGEMENT—BEFORE

“LEGAL” RESTRICTIONS ON VEGETATION MANAGEMENT—AFTER

Effects of Ambient Conditions on Ratings

Situation after Initial Trips 3:05:41 – 3:41:35

Star- S. Canton (3:41:35)
138 kV Lines Overload and Cascade Near Akron

Simulated 138 kV Loadings

% of Normal Ratings (Amps)

Outages

Dale-W.Can 138 kV
W.Ak-PV Q22 138 kV
Cham-W.Ak 138 kV
E.Lima-N.Fin 138 kV
CantC Xfmr W.Ak-PV Q21 138 kV
Babb-W.Ak 138 kV
E.Lima-N.Lib 138 kV
Clov-Torrey 138 kV
Star-S.Canton 345 kV
Hanna-Jun 345 kV
Hard-Cham 345 kV
Cham-W.Ak 138 kV

138 kV Cascade Contributes Further to Overload of Sammis-Star

Sammis-Star Zone 3 Relay Operates on Steady State Overload

Actual Loading on Critical Lines
Actual Voltages Leading to Sammis-Star

Cascade Sequence 1

16:05:57 EDT

Major Path to Cleveland Blocked after Loss of Sammis-Star 4:05:57.5 PM

Cascade Sequence 2

16:05:58 EDT

345 kV Lines Trip Across Ohio to West

Generation Trips 4:09:08 – 4:10:27 PM
Cascade Sequence 6

Power Transfers Shift at 4:10:38.6 PM

Blackout Sequence – Phase 4

Cleveland – Toledo Island 4:10:39 - 4:10:46 PM
Cleveland Blacks Out

Eastern Michigan (Detroit) Unstable Voltage and Frequency Collapse and Pole Slipping

Generator Trips to 16:10:38
Generator Trips – Next 7 Seconds

Overloads on PJM – NY Ties 4:10:39 PM

PJM – NY Separating 4:10:44 PM

Northeast Completes Separation from Eastern Interconnection 4:10:43 – 4:10:45 PM

Conditions at Niagara Indicate Progressively Worsening Stability Conditions with Prior Events

Island Breaks Up: 4:10:46 – 4:13 PM
Cascade Sequence 7

Frequency in Ontario and New York during Breakup
Niagara Generation Stays with Western NY

Frequencies in Separated Areas

Generator Trips – After 16:10:44

Cascade Sequence 8

End of the Cascade

Some Local Load Uninterrupted

Areas Affected by the Blackout: Service restored in some areas
The August 14th Outage

Before

After

Blackout Root Cause Group 1
FE Situational Awareness

- FE did not ensure a reliable system after contingencies occurred because it did not have an effective contingency analysis capability
- FE did not have effective procedures to ensure operators were aware of the status of critical monitoring tools
- FE did not have effective procedures to test monitoring tools after repairs
- FE did not have additional high level monitoring tools after alarm system failed

Blackout Out Root Cause Group 2
Vegetation Management

- FE did not adequately manage tree growth in its transmission rights of way

Blackout Out Report: Vegetation Management

<table>
<thead>
<tr>
<th>Right of Way Width</th>
<th>900 kV</th>
<th>345 kV</th>
<th>230 kV</th>
<th>Less than 230 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum Width (ft)</td>
<td># of Locations</td>
<td>Minimum Width (ft)</td>
<td># of Locations</td>
<td>Minimum Width (ft)</td>
</tr>
<tr>
<td>125-150</td>
<td>46</td>
<td>345</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>150-175</td>
<td>21</td>
<td>175</td>
<td>30</td>
<td>125</td>
</tr>
<tr>
<td>175+</td>
<td>15</td>
<td>175+</td>
<td>30</td>
<td>125+</td>
</tr>
</tbody>
</table>

Blackout Out Report: Vegetation Management

<table>
<thead>
<tr>
<th>Vertical Clearance Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>900 kV</td>
</tr>
<tr>
<td>Clearance (ft)</td>
</tr>
<tr>
<td>0-15</td>
</tr>
<tr>
<td>16-20</td>
</tr>
<tr>
<td>21-25</td>
</tr>
<tr>
<td>26+</td>
</tr>
<tr>
<td>26+</td>
</tr>
</tbody>
</table>
Some Reported Problems:

- Otter Tail Power: FWS and DNR repeatedly planted trees in ROW
- Pacificorp: DOT planted trees in ROW, would not allow them to be pruned
- NY Environmental Dept requires filing for a "temporary revocable permit" to trim trees, requires 2 years to process application

List of Reported Obstacles

<table>
<thead>
<tr>
<th>Reported Obstacles</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>U.S. Forest Service</td>
<td>22</td>
</tr>
<tr>
<td>U.S. Fish and Wildlife Service</td>
<td>12</td>
</tr>
<tr>
<td>National Park Service</td>
<td>6</td>
</tr>
<tr>
<td>Department of Transportation</td>
<td>6</td>
</tr>
<tr>
<td>Federal/State/Local Governments</td>
<td>35</td>
</tr>
<tr>
<td>Private Landowners</td>
<td>20</td>
</tr>
<tr>
<td>Other</td>
<td>10</td>
</tr>
</tbody>
</table>

Blackout Cause Group 3

Reliability Coordinator Diagnostics

- 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 ineffective procedures and wide grid visibility to coordinate problems affecting their common boundaries.