NERC Response

- First hours
  - Working with reliability coordinators – assessing restoration efforts and identifying what had initially tripped
- Began organizing investigation effort
  - Outage covered three NERC regions
  - Established a Steering Group of industry experts
- Became technical lead for the U.S.-Canada Power System Outage Task Force
Investigation Organization Overview

Steering Group

Investigation Team Lead

MAAC/ECAR/NPCC

Coordinating Group

MAAC

ECAR

NPCC

MEN Study Group

Project Planning and Support

Root Cause Analysis

Cooper Systems

Investigation Process Review

Vegetation/ROW Management

Sequence of Events

NERC & Regional Standards/Procedures & Compliance

Restoration

Data Requests and Management

System Modeling and Simulation Analysis

Transmission System Performance, Protection, Control Maintenance & Damage

Generator Performance, Protection, Controls Maintenance & Damage

Sequence of Events

Operations - Tools, SCADA/EMS Communications Op Planning

Frequency/ACE

System Planning, Design, & Studies

Transmission Map Key

Transmission Lines

- 765 kV
- 500 kV
- 345 kV
- 230 kV
Footprints of Reliability Coordinators in Midwest

Warm But Not Unusual for August
August 14 Imports to Northeast (Except ISO-NE, and Maritimes) Compared to 6/1 to 8/13/2003

Voltages Prior to 15:05 EDT August 14
Reactive Power Margins from V-Q Analysis

Transmission Lines
- 765 kV
- 500 kV
- 345 kV
- 230 kV

Reactive Power Margin @ 15:32
Reactive Power Margin @ 15:41

Avon 345kV

Voltage (p.u.)

Reactive Margin

15-05 Chamberlin-Harding
15-32 Hanna-Juniper
15-41 Star-S Canton
15-45-40 Canton Central-Tidd
15-59 West Akron 138kV Lines
East Lake 5 Trip:  1:31:34 PM

East Lake 5 Exciter Failure Causes Trip

Exciter Control trips to manual and backs off overloaded MVAR output

Exciter System trips completely off as operator returns it to automatic voltage control
Stuart Atlanta Trip: 2:02 PM

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 logger fails and operators are not aware
  - No further 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 (59 second 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
Hanna - Juniper Tree Contact
Insufficient Clearance with Trees

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

Juniper ground fault current build up (fault current)

Line Trips

Time = 14.023 mSec

Faulted phase current

Harding - Chamberlain 345 kV fault at 15:05 EDT
DFR recorder taken from Harding - Juniper @ Juniper
Effects of Ambient Conditions on Ratings

- 38' Height @ 5 MPH Winds
- 36' Height @ 0 MPH Winds
- 34' Height @ Emergency Rating

Star-S. Canton (3:41:35)
Actual Loading on Critical Lines

Situation after Initial Trips 3:05:41 – 3:41:35
Actual Voltages Leading to Sammis-Star

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
138 kV Lines Overload and Cascade Near Akron

Simulated 138 kV Line Loadings

% of Normal Ratings (Amps)

Outages

138 kV Cascade Contributes Further to Overload of Sammis-Star

% of Normal Ratings (Amps)
Sammis-Star Zone 3 Relay Operates on Steady State Overload
Last Major Path to Cleveland Blocked after Loss of Sammis-Star 4:05:57.5 PM

Blackout Root Cause Group 1
FirstEnergy Lack of Situational Awareness

- Did not ensure a reliable system after contingencies occurred because it did not have an effective contingency analysis capability
- Did not have effective procedures to ensure operators were aware of the status of critical monitoring tools
- Did not have effective procedures to test monitoring tools after repairs
- Did not have additional high level monitoring tools after alarm system failed
Blackout Out Root Cause Group 2
FirstEnergy Ineffective Vegetation Management

- Did not adequately manage ground clearance (tree clearance) in its transmission rights of way

Blackout Cause Group 3
Reliability Coordinator Ineffective Diagnostics

- Reliability Coordinator (MISO for FE)
  - State estimator failed due to a data error.
  - Flowgate monitoring tool didn’t have real-time line information to detect growing overloads
  - Operators couldn’t easily link breaker status to line status to understand changing conditions.
  - Did not declare emergency or take any action
- PJM & MISO ineffective procedures & wide grid visibility to coordinate problems affecting their common boundaries
345 kV Lines Trip Across Ohio to West
4:08:59 - 4:09:07 PM

Generation Trips 4:09:08 - 4:10:27 PM
**345 kV Transmission Cascade Moves North into Michigan 4:10:36 – 4:10:37 PM**

Northern Ohio and Eastern Michigan Served Only from Ontario after 4:10:37.5 – 4:10:38.6 PM
Power Transfers Shift at 4:10:38.6 PM

New York to Ontario 345 kV Line Flows at Niagara
Progressively Worsening Stability Conditions

New York to Ontario 345 kV Line Flow at Niagara
(does not include 230 kV line flow)
Cleveland – Toledo Island 4:10:39 - 4:10:46 PM
Cleveland Blacks Out

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

Ontario – Michigan Interface Flow and Voltages Beginning 16:10:38
Severe Under Frequency Condition

View Into Detroit from Lambton
Northeast Completes Separation from Eastern Interconnection  4:10:43 – 4:10:45 PM

Power plants affected

1. 531 units shut down at 263 plants
2. During the conclusion of the cascading failure, generation tripped off in three general categories:
   1. Excitation system overload or extreme low voltage – 35%
   2. Generator protection or control system action – 34%
   3. Consequential result of the broken transmission system – 31%
3. Some prolonged out-of-step conditions are evident
4. To date, little damage has been discovered as a result of the cascade
Frequency in Ontario and New York

Island Breaks Up: 4:10:46 – 4:13 PM
End of the Cascade

Areas Affected by the Blackout
Service maintained in some area

Some Local Load Interrupted

When the Cascade Was Over

- 50 million people
  8 states and 2 provinces
- 60-65,000 MW of load initially interrupted
  - Approximately 11% of Eastern Interconnection
- Sammis – Star trip at 4:06 PM – Blackout essentially complete by 4:13 PM
- High speed cascading lasted approximately 12 seconds
- Thousands of discrete events to evaluate
  - Time stamping - critical
Violations of NERC Reliability Standards

- FE did not return the system to safe operating state within 30 minutes (OP-2)
- FE did not notify others of impending emergency (OP-5)
- FE did not have effective monitoring capability (OP-5)
- FE did not adequately train operating personnel for emergency response (OP-8)
- MISO did not notify others of impending emergency (OP-9)

Other Key Findings of Investigation

- Compliance with reliability rules requires objective measurements and firm actions to resolve violations
- NERC policies were not sufficiently specific regarding reliability coordinator and control area functions, responsibilities, authorities, tools
- Problems from prior wide-area blackouts are being repeated: trees, operator tools, training
Other Key Findings of Investigation

- System planning and design studies, operations planning, facilities ratings, and modeling data accuracy were ineffective preparations for 8/14 event
- Power system in northeastern Ohio was being operated with insufficient reactive margins to meet NERC criteria
- Protection and controls could be more effectively used to slow or minimize spread of cascade

Corrective Actions - FE

- Voltage criteria and reactive resources
- Operational preparedness and action plan
- Emergency response capabilities and preparedness
- Control center and operator training
Corrective Actions – Reliability Coordinators

- MISO
  - Reliability tools
  - Visualization tools
  - Operator training
  - Communications protocols and procedures
  - Operating agreements
- PJM
  - Communications protocols and procedures

NERC Strategic Initiatives

- Performance reviews
- Readiness audits
- Vegetation-related outage reporting
- Recommendations implementation tracking
NERC Technical Initiatives - 1

- Operator and reliability coordinator emergency response training
- Reactive power and voltage control
- Cascade mitigation
- Reliability coordinator and control area functions, authorities, and requirements
- Real-time operating tools
- Restoration review

NERC Technical Initiatives - 2

- Time-synchronized measurements for disturbance analysis and operations
- Reevaluate system design, planning and operating criteria
- System modeling and data exchange standards