NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

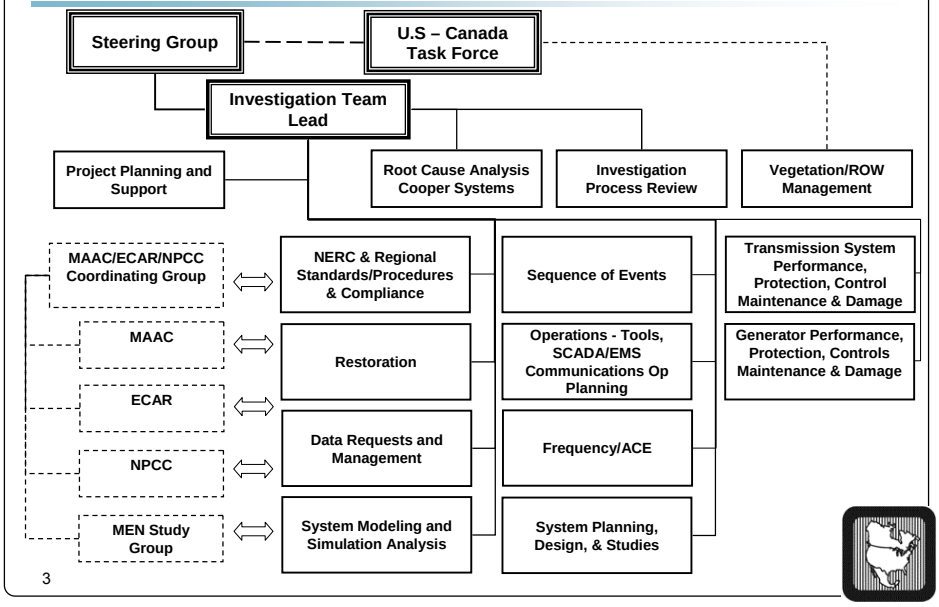
NERC Response

- 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

2

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

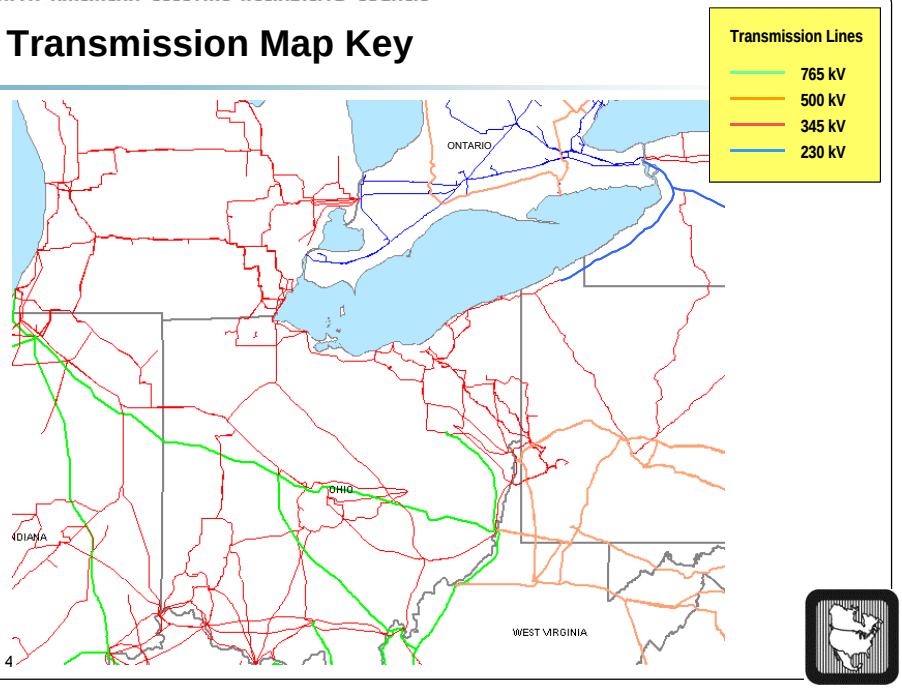
Investigation Organization Overview



3

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

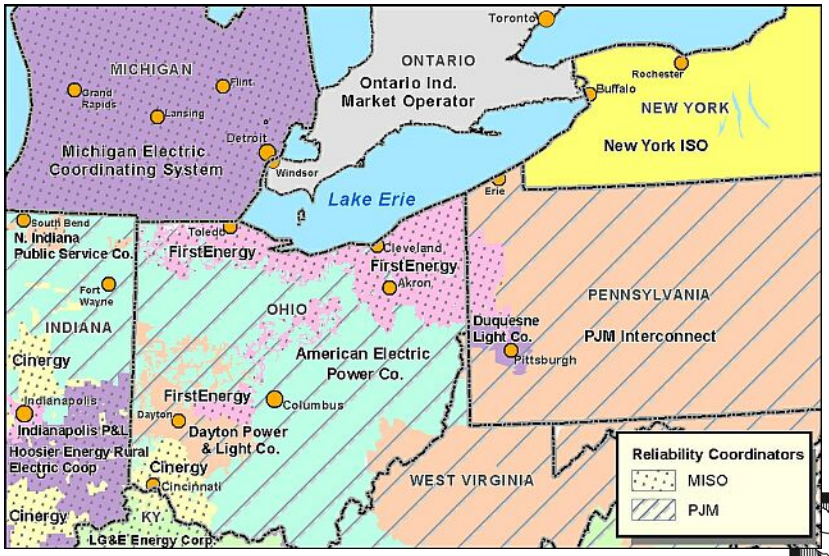
Transmission Map Key



4

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

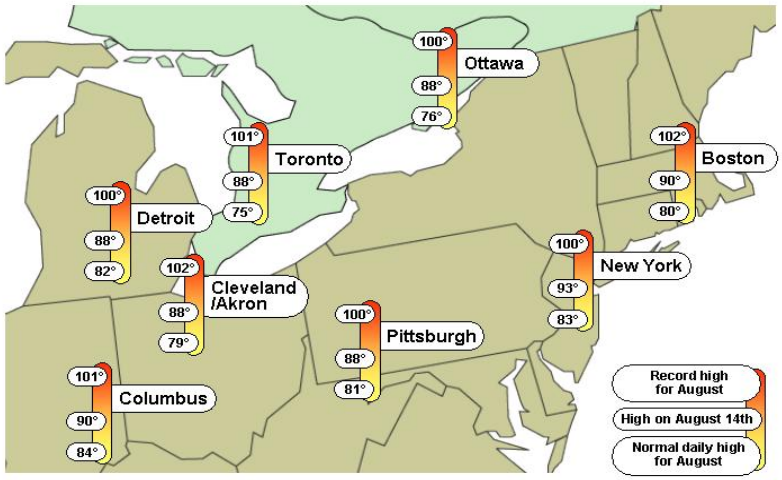
Footprints of Reliability Coordinators in Midwest



5

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

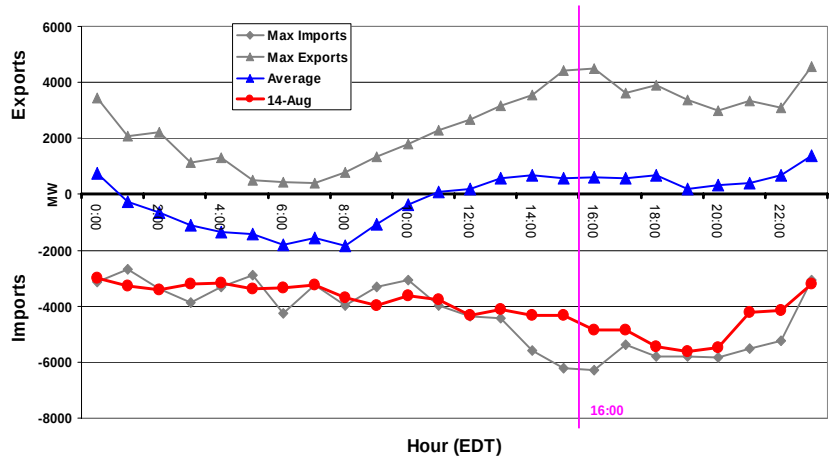
Warm But Not Unusual for August



6

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

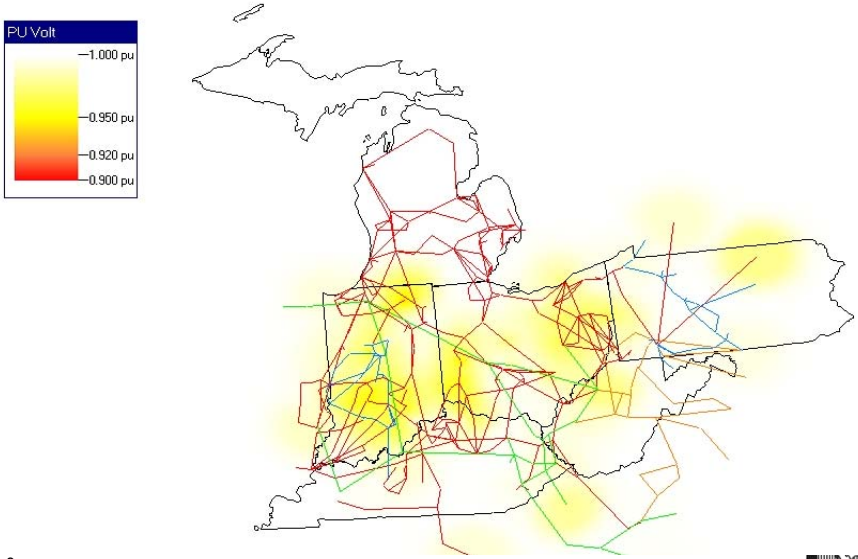
August 14 Imports to Northeast (Except ISO-NE, and Maritimes) Compared to 6/1 to 8/13/2003



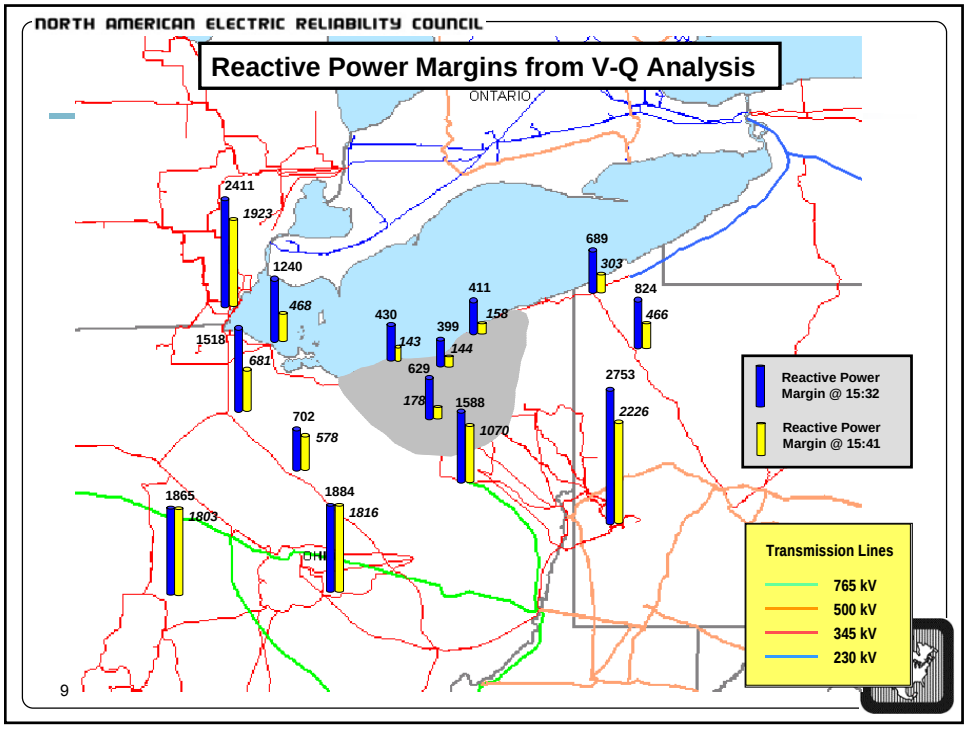
7

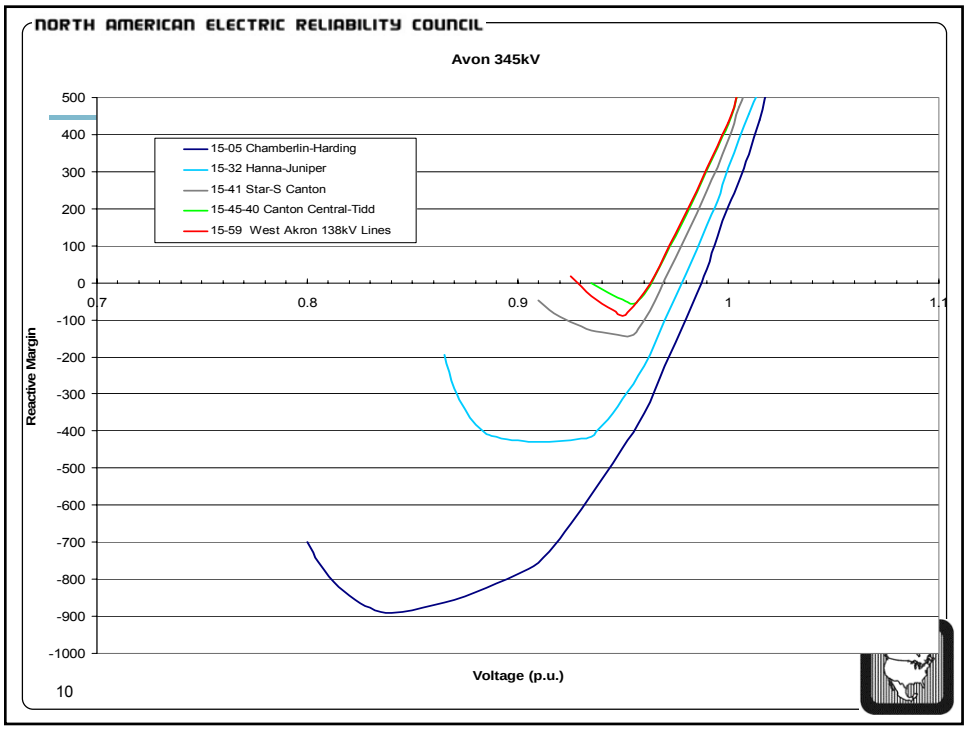
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Voltages Prior to 15:05 EDT August 14



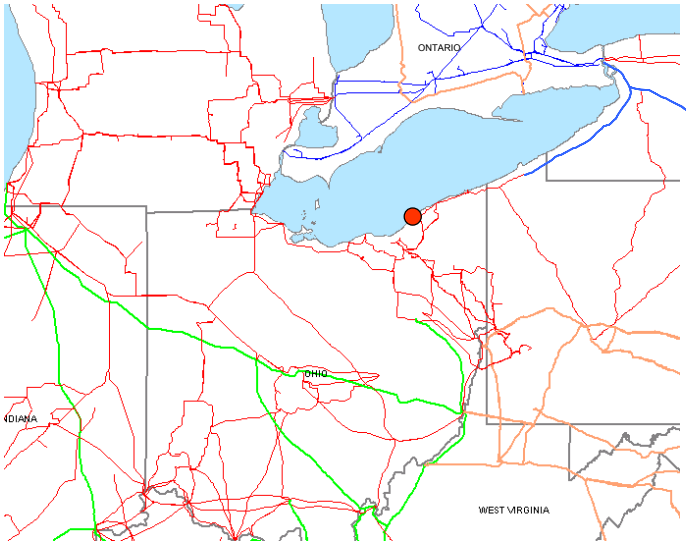
8


NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL
Reactive Power Margins from V-Q Analysis
ONTARIO
2411
1923
1240
468
1518
681
430
143
399
144
411
158
629
178
1588
1070
702
578
1865
1803
1884
1816
689
303
824
466
2753
2226
Reactive Power Margin @ 15:32
Reactive Power Margin @ 15:41
Transmission Lines
765 kV
500 kV
345 kV
230 kV
9


NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL
Avon 345kV
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
Reactive Margin
Voltage (p.u.)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1000
0.7
0.8
0.9
1
1.1
10

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

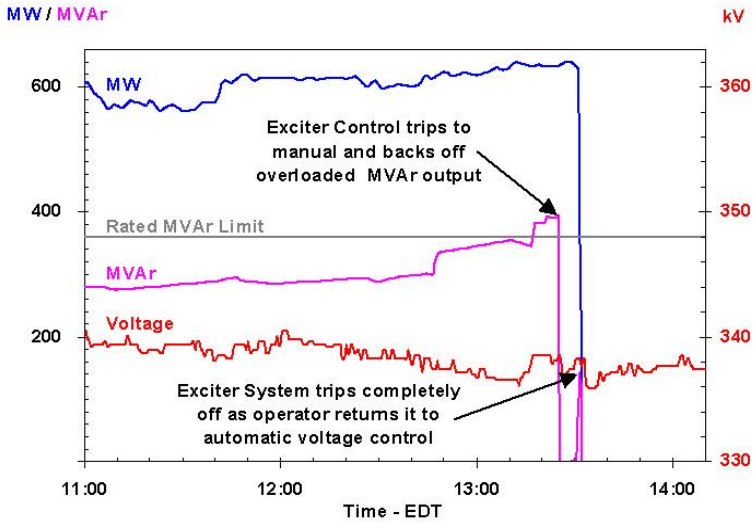
East Lake 5 Trip: 1:31:34 PM



11

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

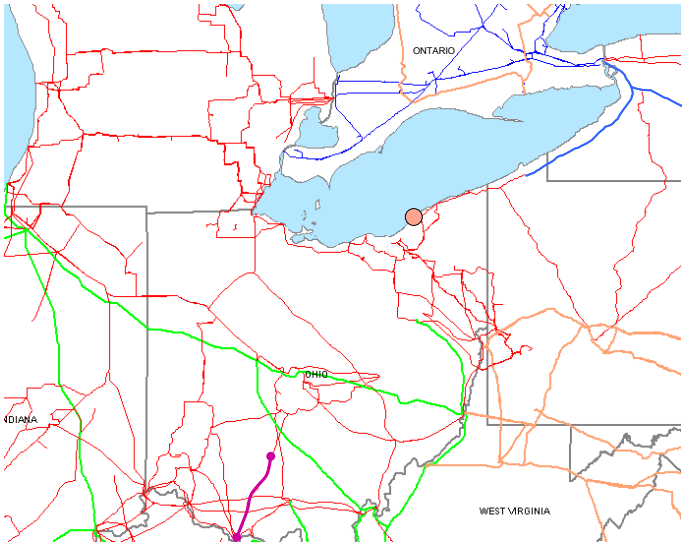
East Lake 5 Exciter Failure Causes Trip



12

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Stuart Atlanta Trip: 2:02 PM



13

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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

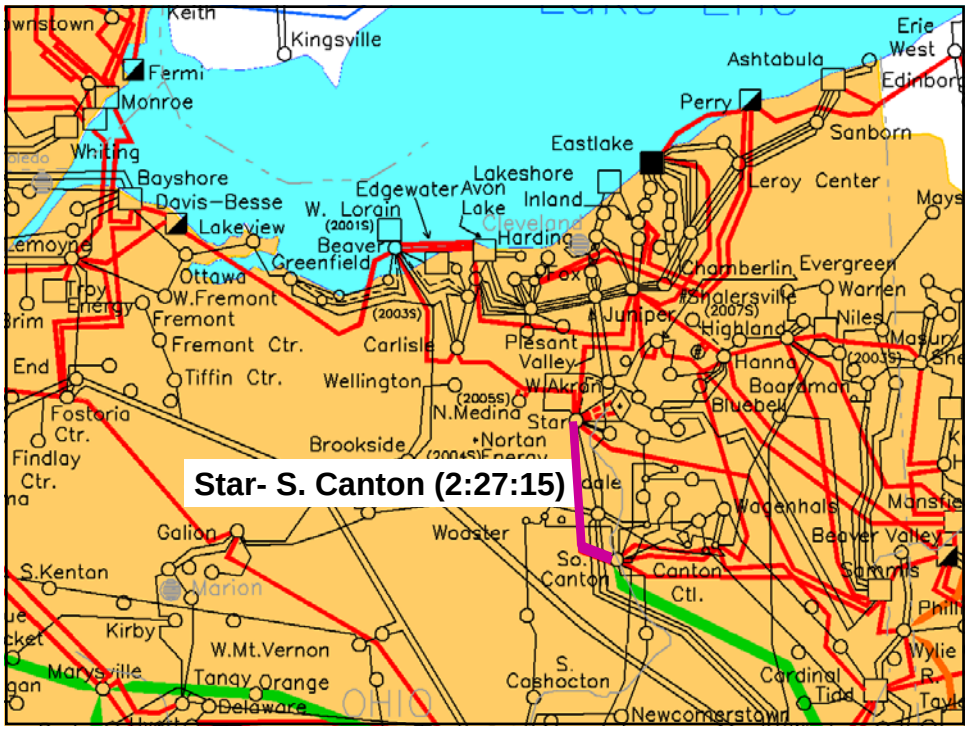
14

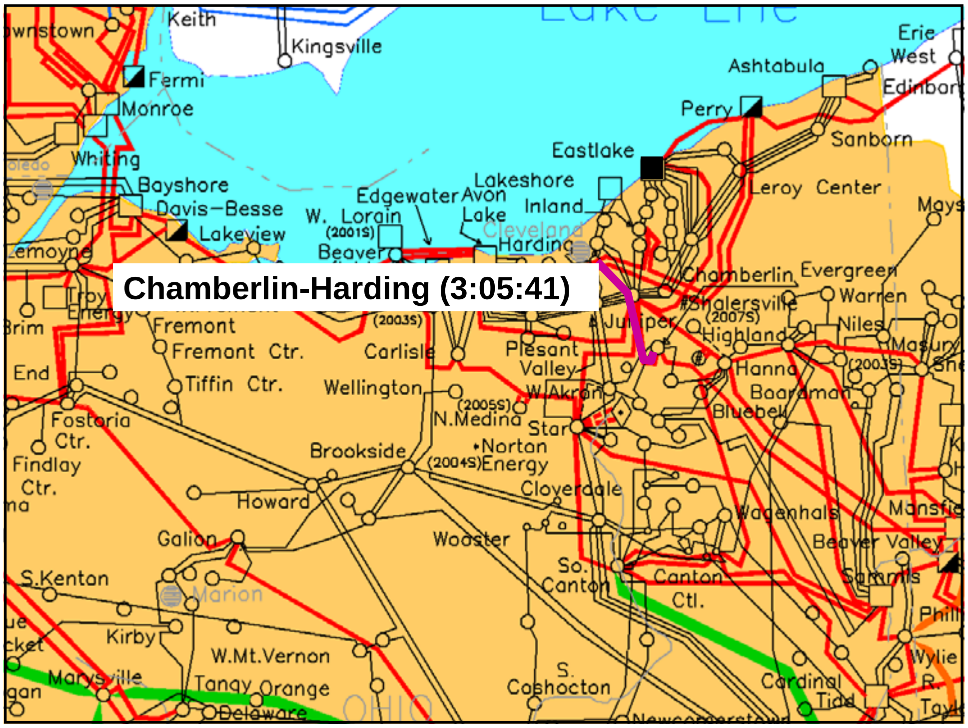
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

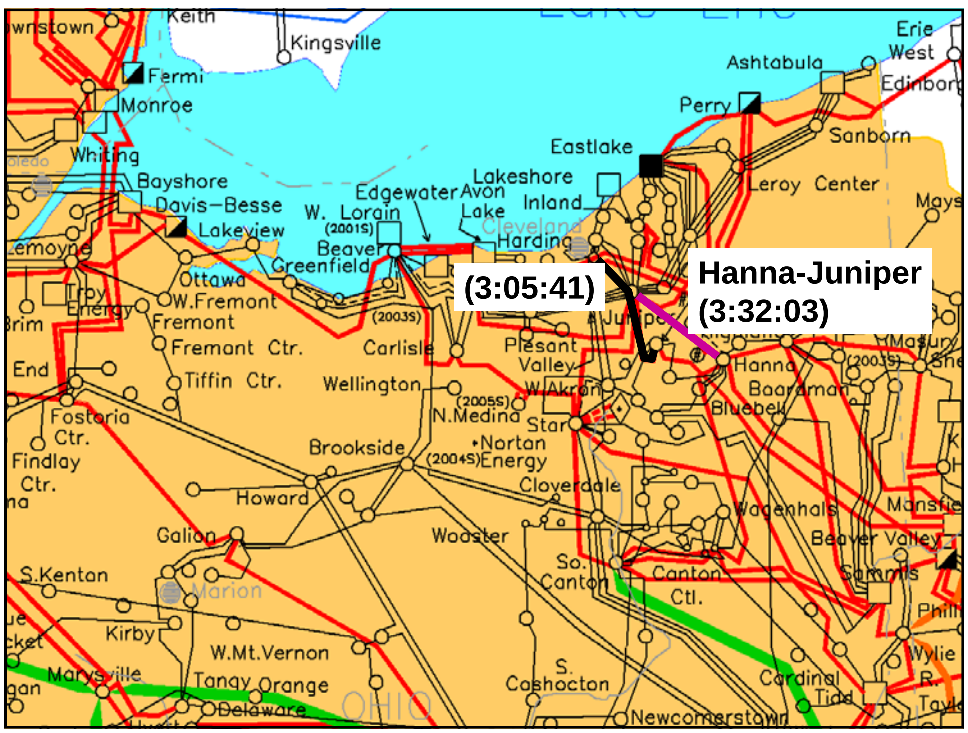
FirstEnergy Computer Failures

- 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

15




Chamberlin-Harding (3:05:41)
Keith
Kingsville
Erie West
Ashtabula
Fermi
Monroe
Perry
Sanborn
Eastlake
Bayshore
Davis-Besse
Lakeview
Lakeshore
Edgewater
Avon Lake
Inland
W. Lorain
(2001S)
Beaver
Harding
Leroy Center
Chamberlin
Evergreen
Warren
Fremont
Fremont Ctr.
Carlisle
Juniper
Highland
Niles
Hanna
Boardman
Bluebell
(2003S)
(2005S)
(2004S)
(2007S)
Tiffin Ctr.
Wellington
Plesant Valley
W.Akron
N.Medina
Star
Fostoria Ctr.
Findlay Ctr.
Brookside
Norton Energy
Cloverdale
Howard
Galion
Wooster
Wagenhals
Beaver Valley
So. Canton
Canton Ctl.
S.Kenton
Marion
Kirby
W.Mt.Vernon
Marysville
Tangy
Orange
Delaware
OHIO
S. Coshocton
Cardinal
Tidd
End


(3:05:41)
Hanna-Juniper (3:32:03)
Keith
Kingsville
Erie West
Ashtabula
Fermi
Monroe
Perry
Sanborn
Eastlake
Bayshore
Davis-Besse
Lakeview
Lakeshore
Edgewater
Avon Lake
Inland
W. Lorain
(2001S)
Beaver
Harding
Greenfield
Ottawa
W.Fremont
Fremont
Fremont Ctr.
Carlisle
Leroy Center
Hanna
Boardman
Bluebell
(2003S)
(2005S)
(2004S)
Tiffin Ctr.
Wellington
Plesant Valley
W.Akron
N.Medina
Star
Fostoria Ctr.
Findlay Ctr.
Brookside
Norton Energy
Cloverdale
Howard
Galion
Wooster
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So. Canton
Canton Ctl.
S.Kenton
Marion
Kirby
W.Mt.Vernon
Marysville
Tangy
Orange
Delaware
OHIO
S. Coshocton
Newcomerstown
Cardinal
Tidd
End

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Hanna - Juniper Tree Contact
Insufficient Clearance with Trees

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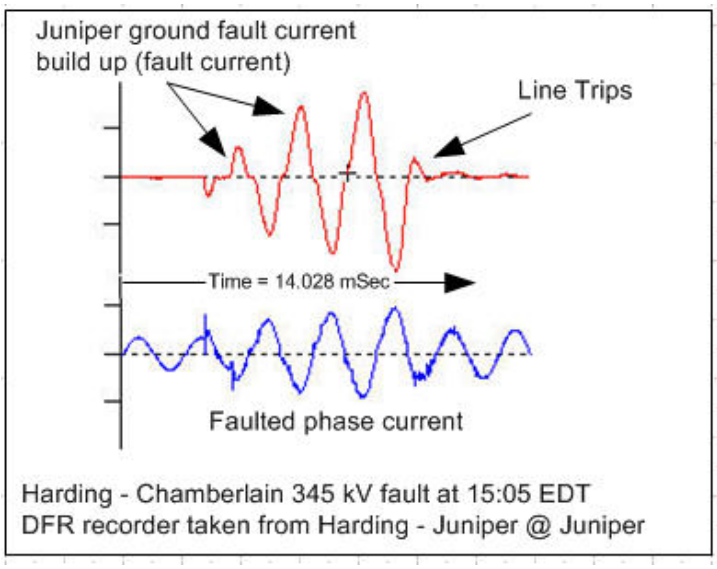
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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



Harding - Chamberlain 345 kV fault at 15:05 EDT
DFR recorder taken from Harding - Juniper @ Juniper

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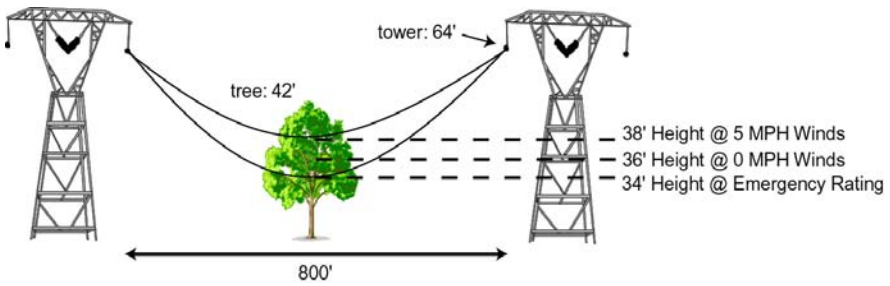
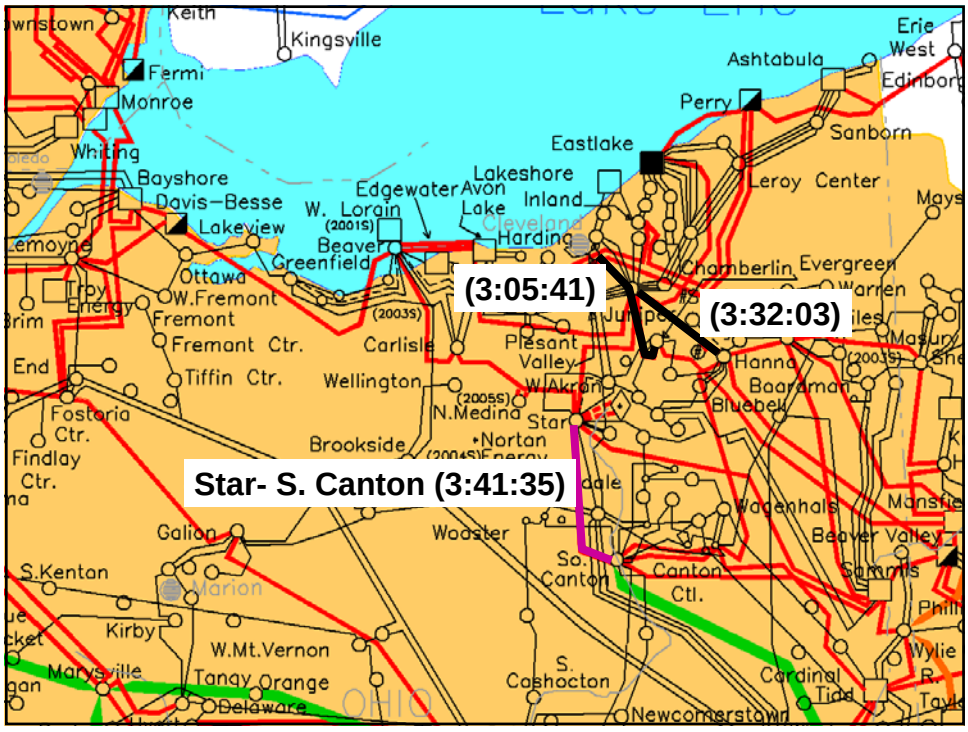
Effects of Ambient Conditions on Ratings

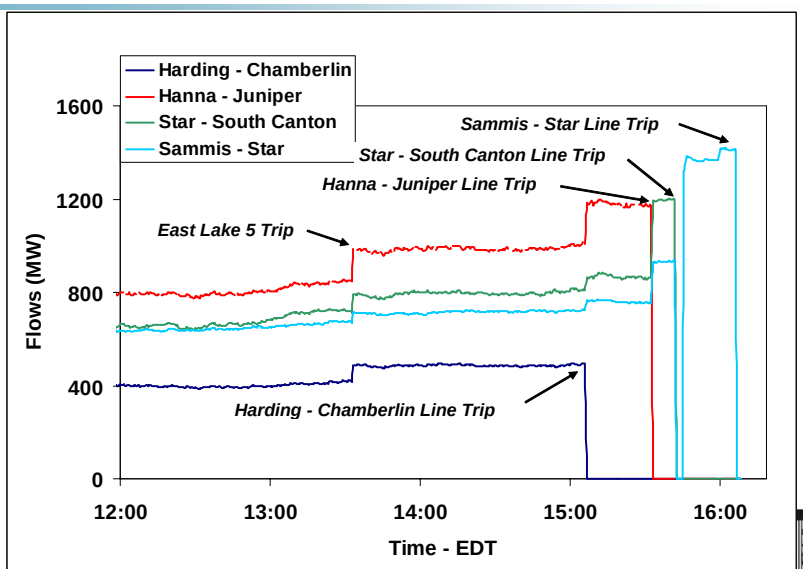


21



NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Actual Loading on Critical Lines



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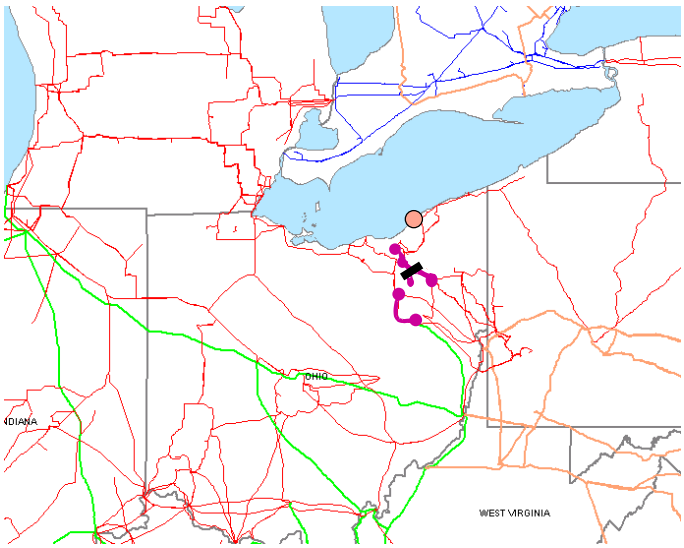
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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



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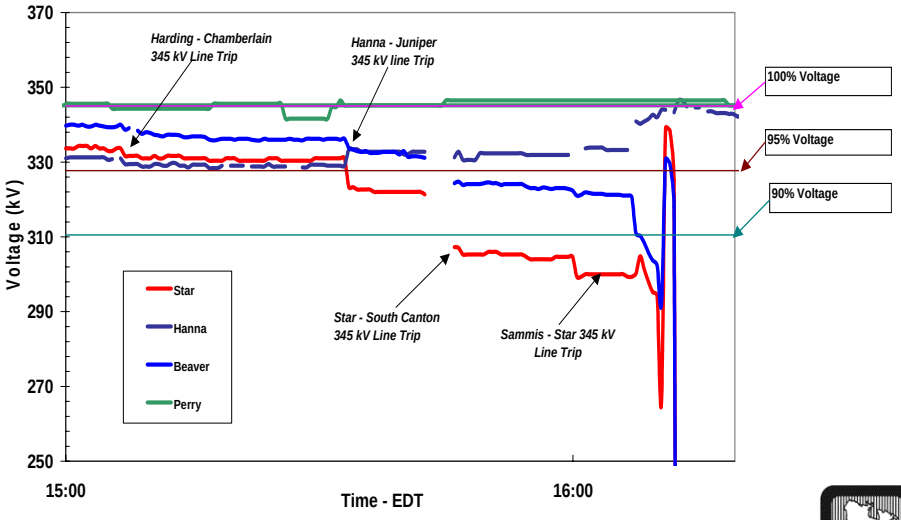
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Actual Voltages Leading to Sammis-Star



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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

26

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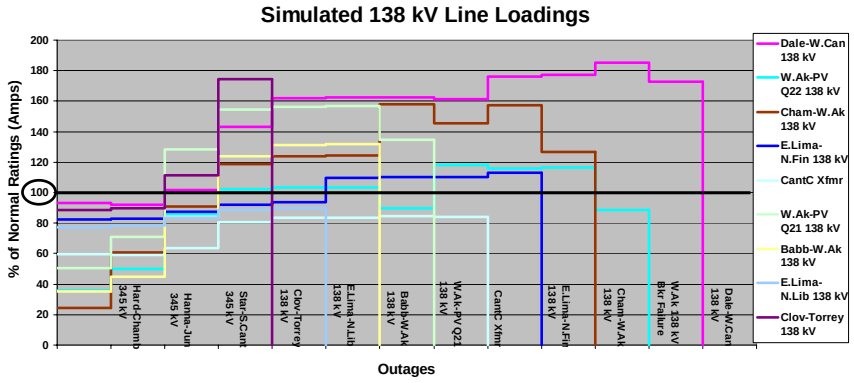
138 kV Lines Overload and Cascade Near Akron



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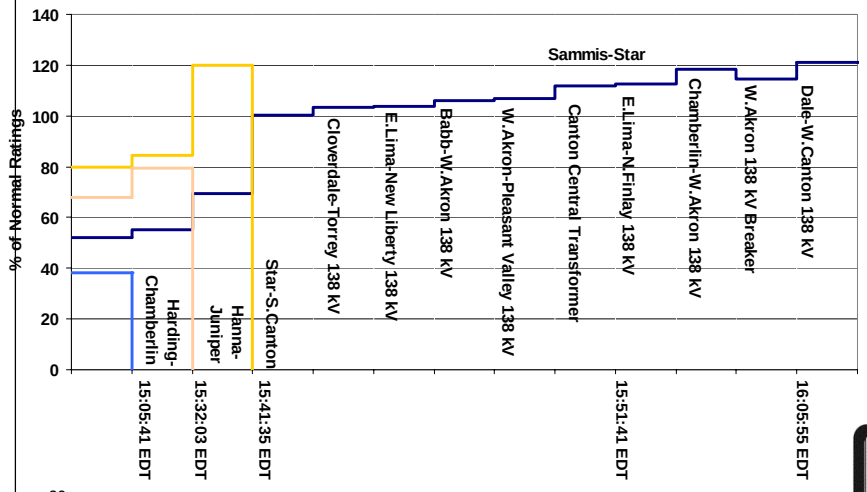
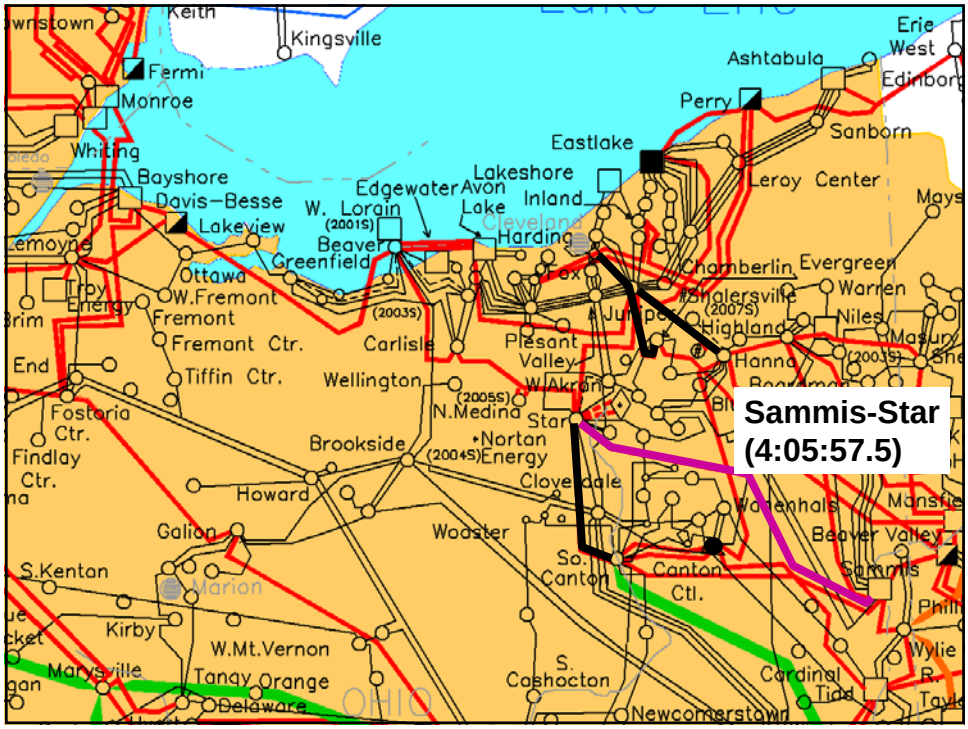
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

138 kV Cascade Contributes Further to Overload of Sammis-Star

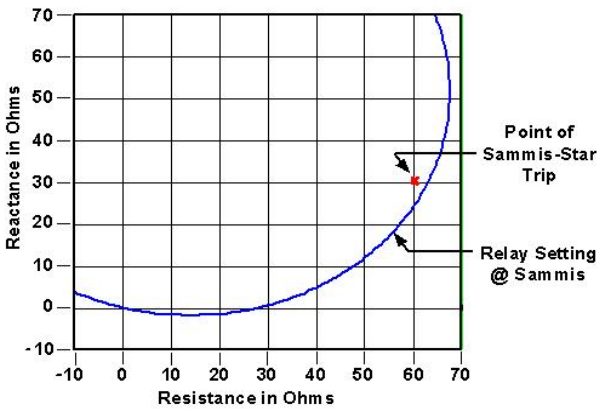


28



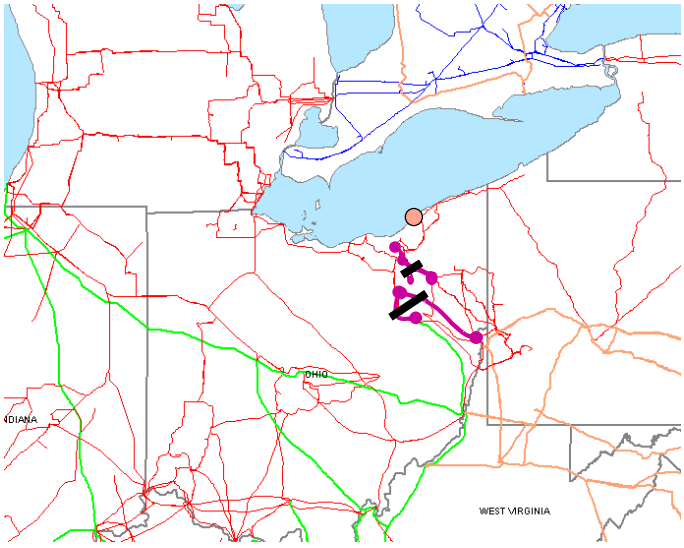
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Sammis-Star Zone 3 Relay Operates on Steady State Overload



NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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



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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

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Blackout Out Root Cause Group 2
FirstEnergy Ineffective Vegetation Management

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

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NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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

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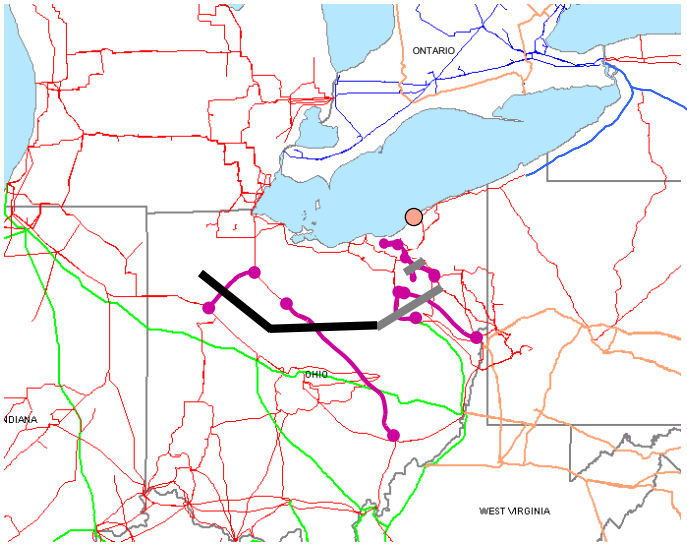
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

345 kV Lines Trip Across Ohio to West 4:08:59 - 4:09:07 PM



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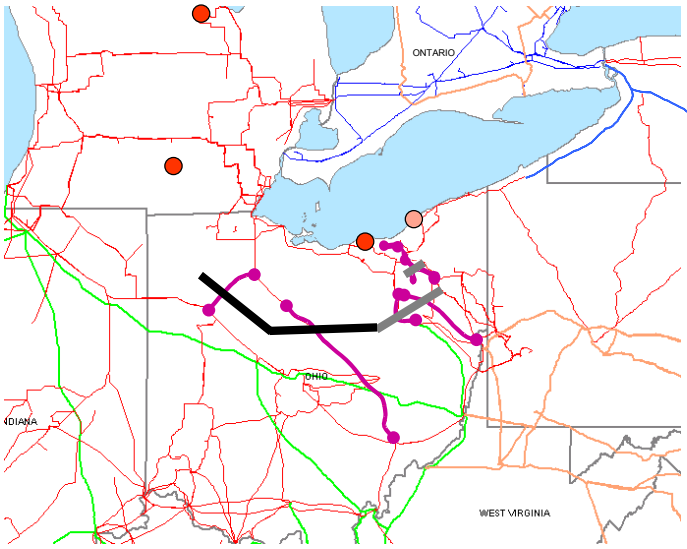
Generation Trips 4:09:08 – 4:10:27 PM



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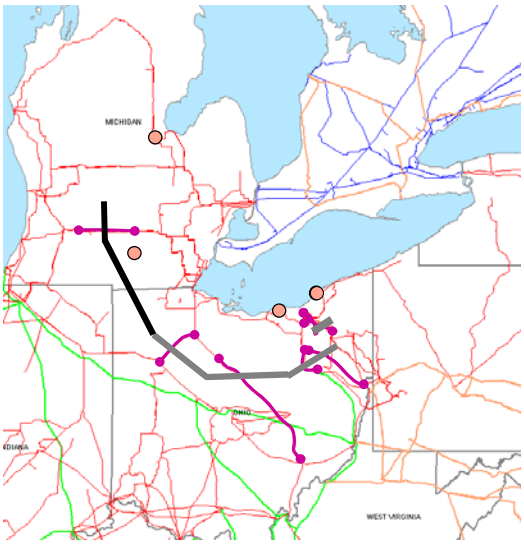
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

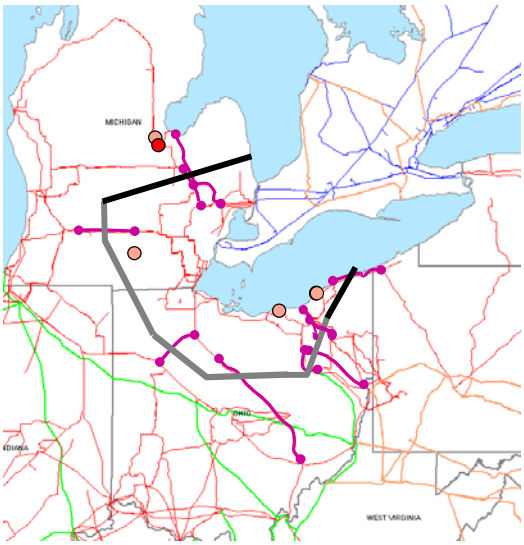
345 kV Transmission Cascade Moves North into Michigan 4:10:36 – 4:10:37 PM



37

NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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



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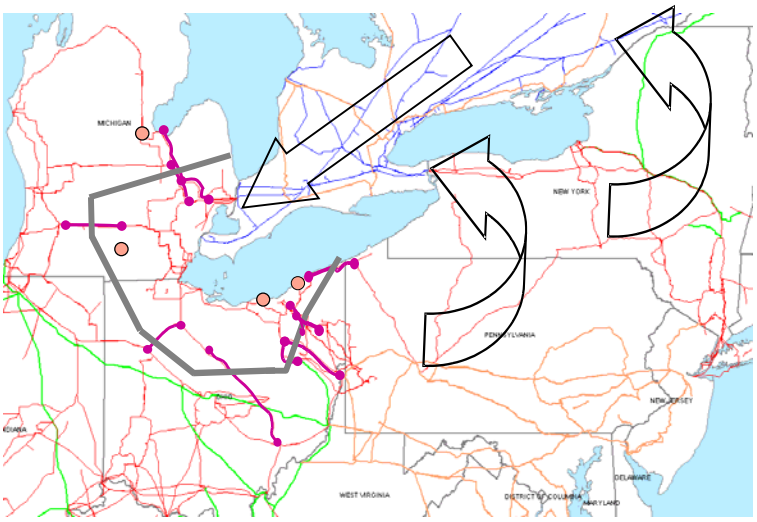
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Power Transfers Shift at 4:10:38.6 PM



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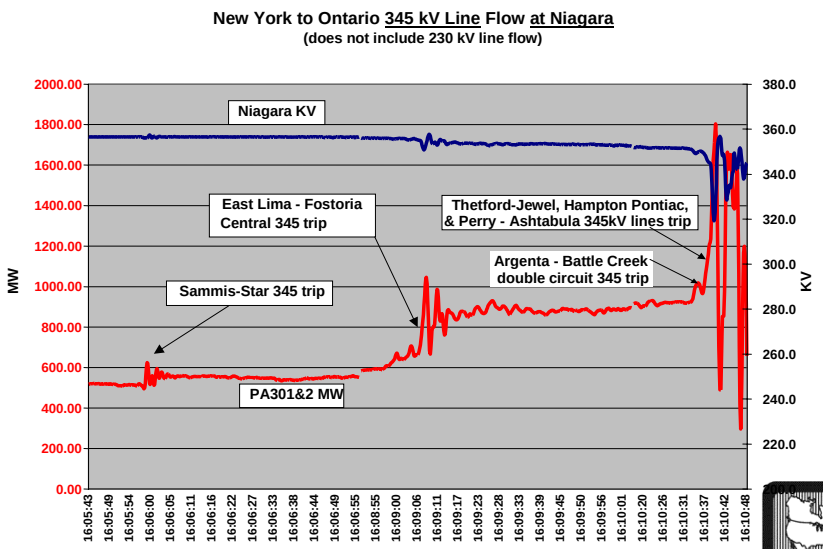
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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



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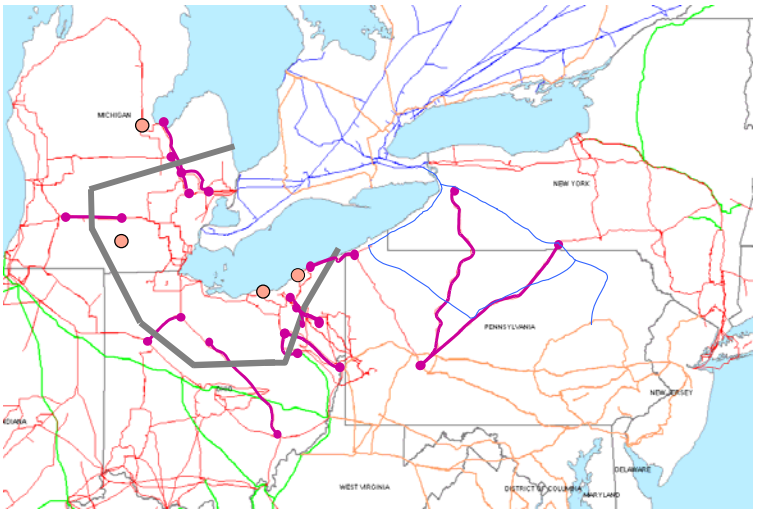
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Power Surge on PJM – NY Ties 4:10:39 PM



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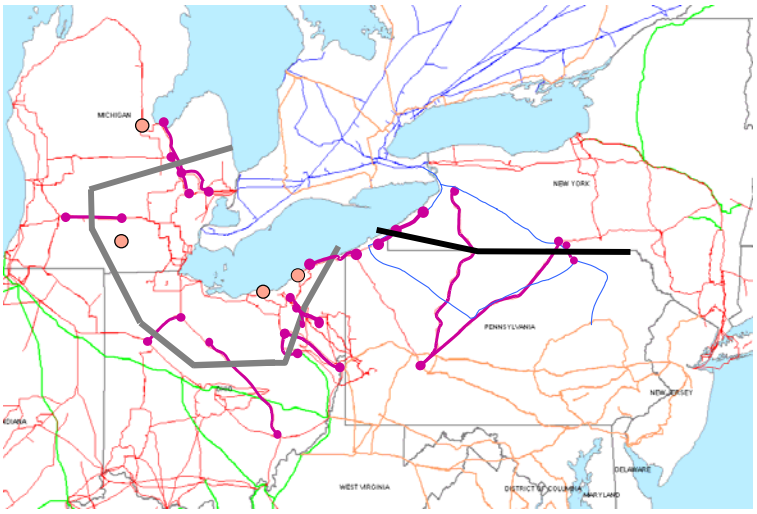
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

PJM – NY Separating 4:10:44 PM



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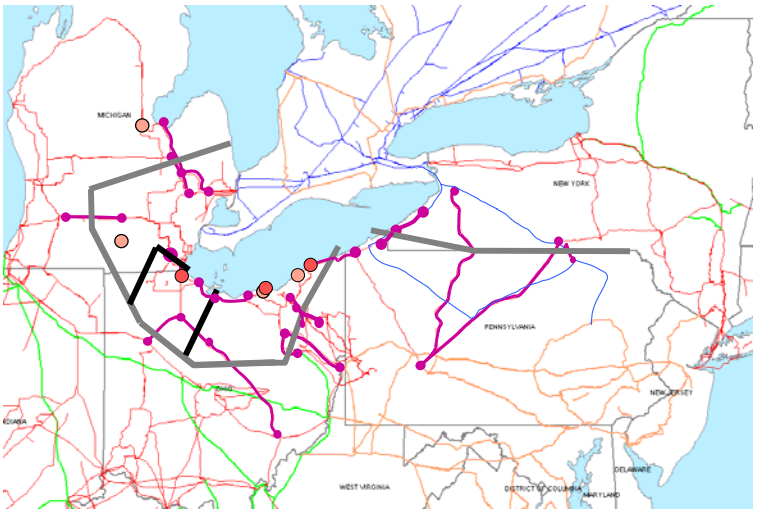
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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



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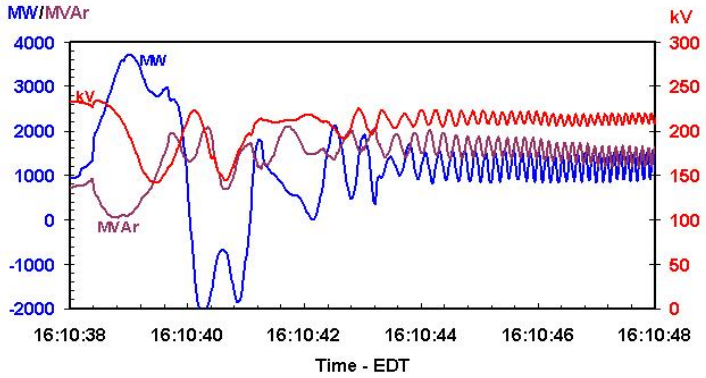
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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

Ontario – Michigan Interface Flow and Voltages Beginning 16:10:38



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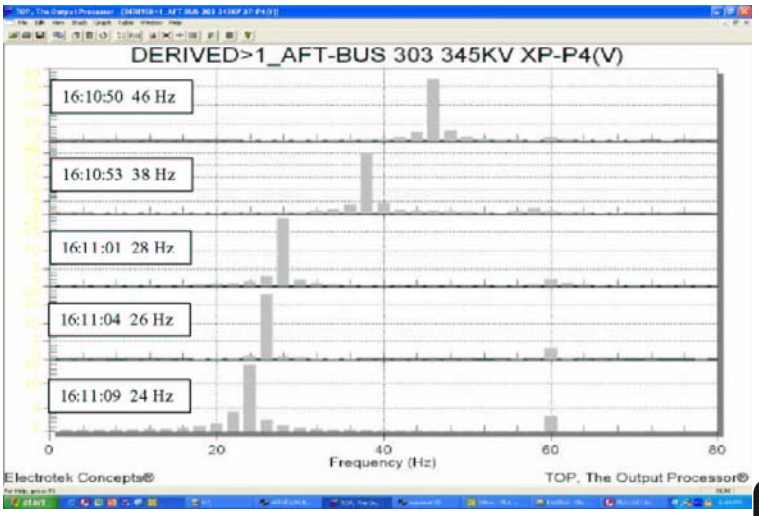
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

Severe Under Frequency Condition



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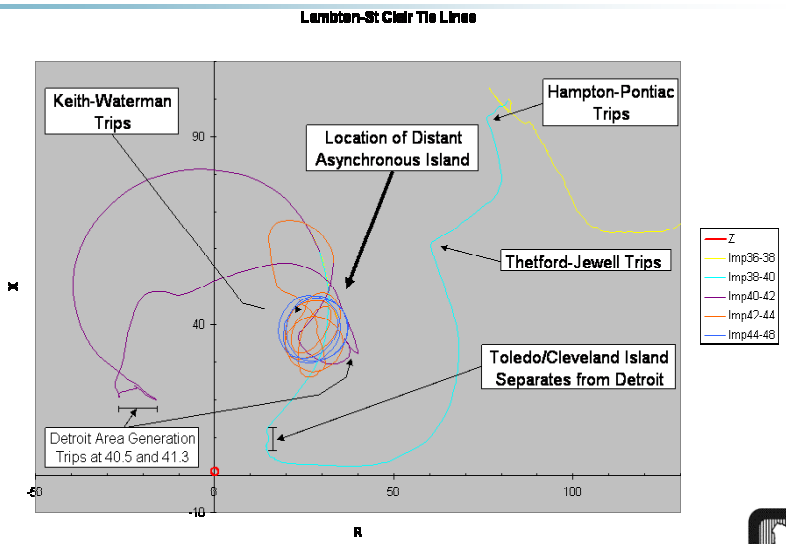
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

View Into Detroit from Lambton



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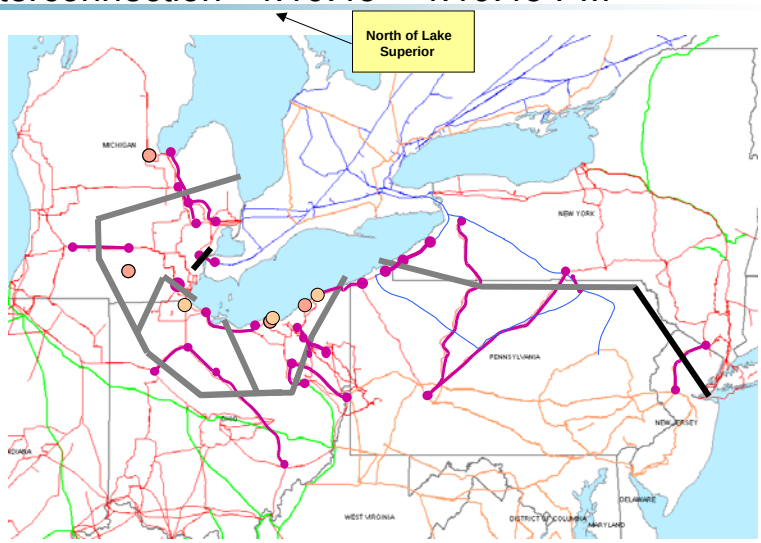
NORTH AMERICAN ELECTRIC RELIABILITY COUNCIL

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



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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

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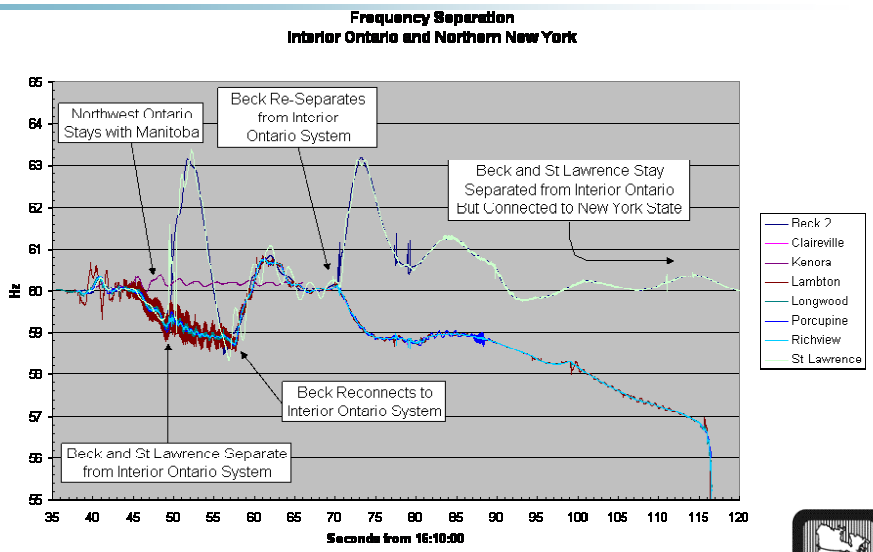
Frequency in Ontario and New York



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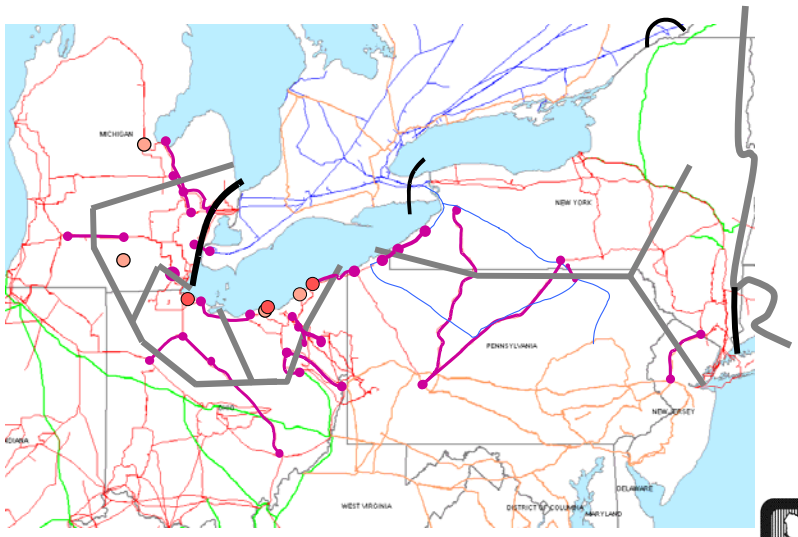
Island Breaks Up: 4:10:46 – 4:13 PM



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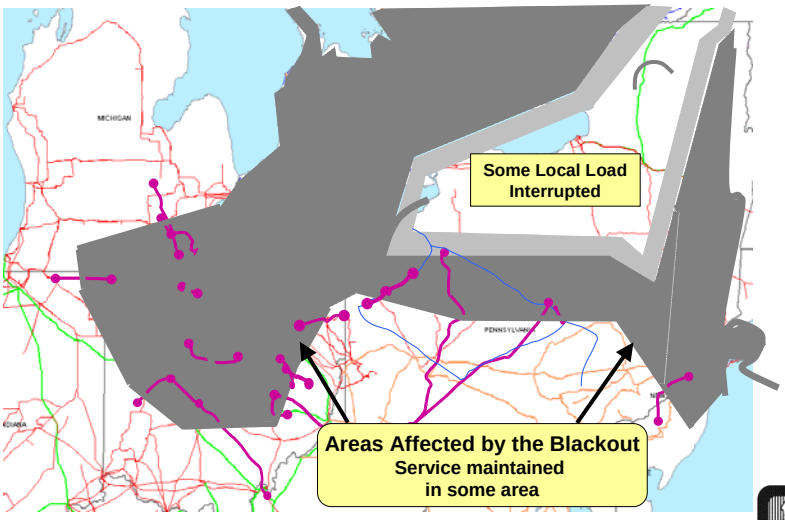
End of the Cascade



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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

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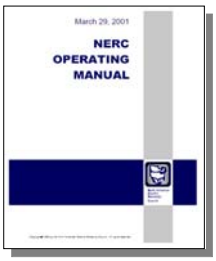
Violations of NERC Reliability Standards

- 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)



Operating Policies

- FE did not adequately train operating personnel for emergency response (OP-8)
- MISO did not notify others of impending emergency (OP-9)

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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

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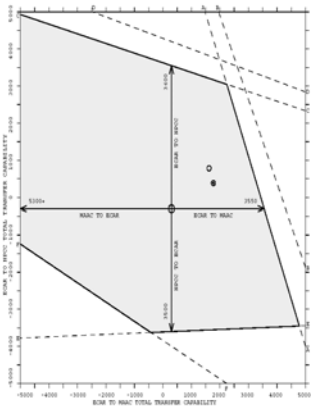
Other Key Findings of Investigation



- 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

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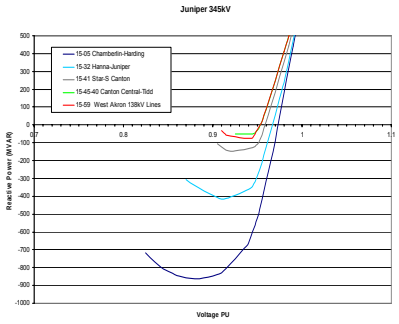
Corrective Actions - FE

- Voltage criteria and reactive resources
- Operational preparedness and action plan
- Emergency response capabilities and preparedness
- Control center and operator training



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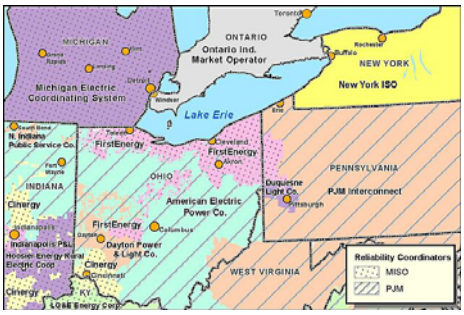
Corrective Actions – Reliability Coordinators

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



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NERC Strategic Initiatives

- Performance reviews
- Readiness audits
- Vegetation-related outage reporting
- Recommendations implementation tracking

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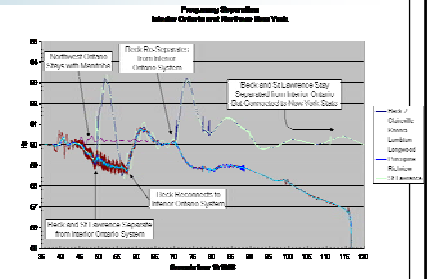
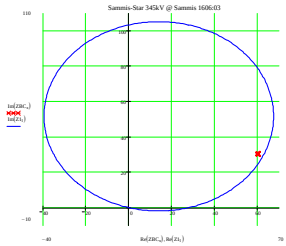
NERC Technical Initiatives - 1

- 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





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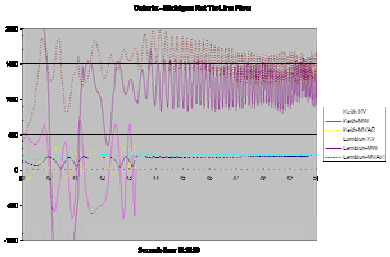
NERC Technical Initiatives - 2

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



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