ECEN 615
Methods of Electric Power Systems Analysis

Lecture 12: August 14, 2003 Blackout

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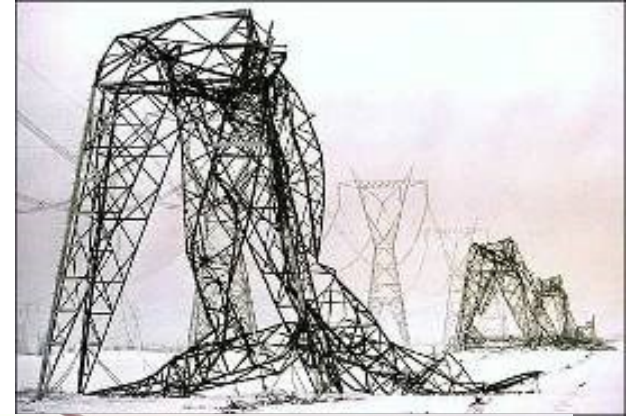
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Announcements

- Read Chapter 7 from the book (the term reliability is now used instead of security)

- Homework 3 should be done before the exam put does not need to be turned in

- First exam is Tuesday October 8 in class; closed book, closed notes. One 8.5 by 11 inch note sheet and calculators allowed
  - The exam from 2018 has been posted
  - Exam covers up to the end of Lecture 11

On Board Sparse Vector Example

Blackouts

- Blackouts are costly, with some estimates of costs above $100 billion per year.

- But blackouts are not created equal. Some are unavoidable due to large scale system damage (hurricanes, tornados and ice storms). Most are local, distribution issues.
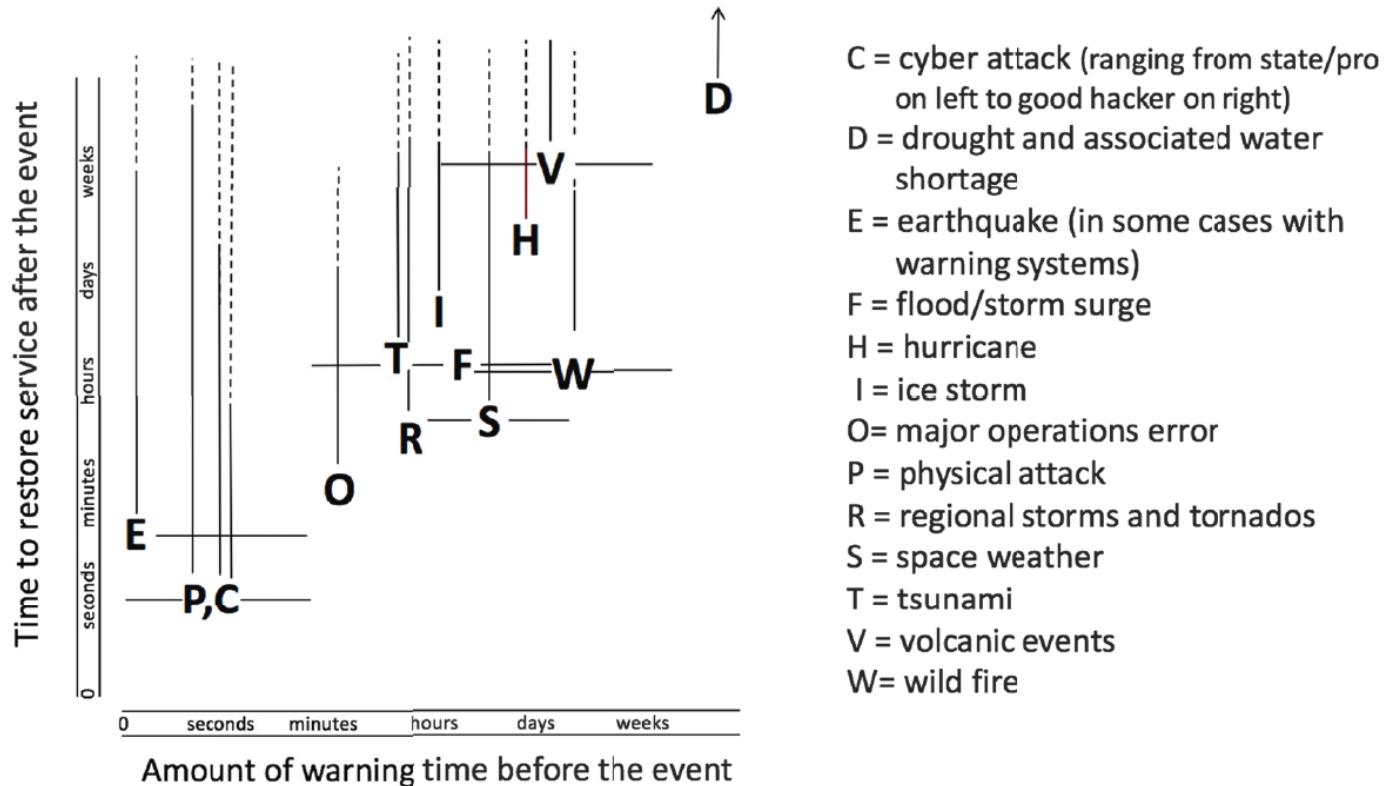
Some Electric Grid Risks

C = cyber attack (ranging from state/pro on left to good hacker on right)
D = drought and associated water shortage
E = earthquake (in some cases with warning systems)
F = flood/storm surge
H = hurricane
I = ice storm
O = major operations error
P = physical attack
R = regional storms and tornados
S = space weather
T = tsunami
V = volcanic events
W = wild fire

FIGURE 3.1 Mapping of events that can cause disruption of power systems. The horizontal placement provides some indication of how much warning time there may be before the event. The vertical axis provides some indication of how long it may take to recover after the event. Lines provide a representation

Image Source: Enhancing the Resilience of the Nation's Electricity System, US National Academies Press, 2017

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The Real Cause of Most Blackouts!

But mostly only the small ones in the distribution system

Photo source: http://save-the-squirrels.com

High-Impact, Low-Frequency Events

- In order to enhance electric grid resiliency we need to consider the almost unthinkable events

- These include what the North American Electric Reliability Corporation (NERC) calls High-Impact, Low-Frequency Events (HILFs); others call them black sky days
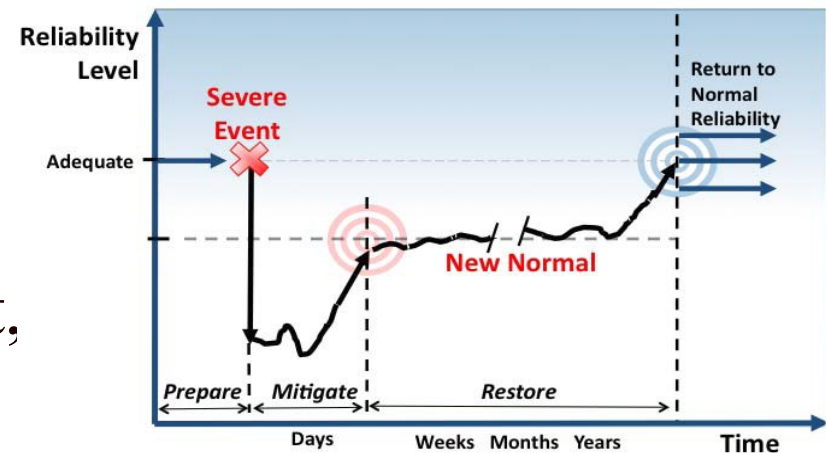

Image Source: NERC, 2012

  – Large-scale, potentially long duration blackouts
  – HILFs identified by NERC were 1) a coordinated cyber, physical or blended attacks, 2) pandemics, 3) geomagnetic disturbances (GMDs), and 4) HEMPs

Avoidable Transmission Level Blackouts

- Many major blackouts can be prevented.

- Time frames of the blackouts, minutes to hours, allow for human intervention

    - Tokyo 1987 (20 minutes), WECC 1996 (six minutes), Eastern Interconnect 2003 (about an hour), Italy 2003 (25 minutes)

- And of course many are prevented, and hence do not make the news. For example, near voltage collapse in Delmarva Peninsula, 1999.

Going Back in Time

- The August 14th 2003 blackout is rapidly moving from being a "recent event" into history; yet it still has much to teach us.

- This talk is about the past and the future: what can we learn from the past to help us prepare for the future
  - But not so much about what are the immediate lessons from the Blackout since many recommendations have already been put into practice.

- The blackout final report is very readable and available by googling "August 14 2003 Blackout Report"

Blackout misery

50 million affected in Northeast and beyond as power grid fails

Transportation Many 'wait it out,' by air and land ■ 4A | **Scenes** Moms in labor, cars stuck in car washes ■ 5A | **Impact** Offices close, ATMs idle, cellphones jam ■ 1B


By Chad Rachman, New York Post, via AP

Brooklyn Bridge: Thousands of commuters in New York took to their feet Thursday evening after a major power outage hit the city and much of the Northeast.

In contrasting numbers, the August 14 2003 Blackout hit about 50 million people, while Hurricane Irene (2011) caused power outages affecting perhaps seven or eight million.

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August 14, 2003 Hoax Image

003/45/7844

ISAT GeoStar 45
23:15 EST 14 Aug. 2003
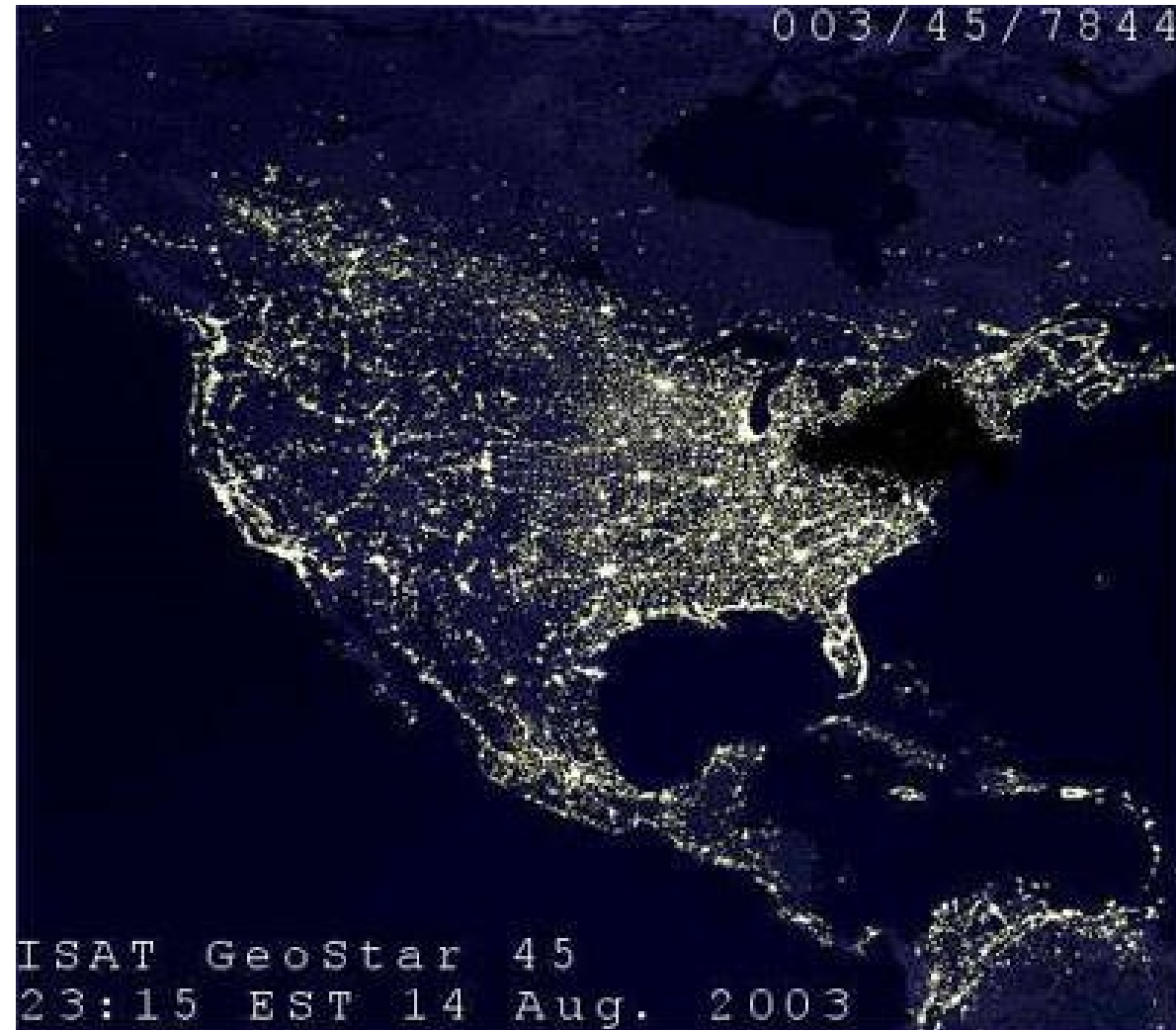
This image was widely circulated immediately after the blackout, even appearing for a time on a DOE website. It was quickly shown to be a hoax.

What might immediately give it away?

Actual Before and After Images

Causes of the Blackout

- Blackout Final Report listed four causes
  - FirstEnergy (FE) did not understand inadequacies of their system, particularly with respect to voltage instability.
  - Inadequate situational awareness by FE
  - FE failed to adequately manage their tree growth
  - Failure of the grid reliability organizations (primarily MISO) to provide effective diagnostic support
- Human/cyber interactions played a key role

We've Come Quite a Ways Since 2003

- Report included 46 recommendations, many of which have dramatically changed the operation of the interconnected power grid
  - Thirteen were focused on physical and cyber security
- Focus of talk is what can 8/14/03 teach us to help with the grid in 2013
- Need to keep in mind economic impact of 8/14/03 was above $5 billion; yearly impact of blackouts could be above $100 billion

First Energy Control Center, Recent (late 2000's)

Photo source: http://blog.cleveland.com/business/2008/12/firstenergy_corp_rejects_puco.html

My Involvement in Blackout Investigation

- I spend a lot of time talking to reporters on 8/14 to 8/16, before I knew what happened

- Tasked by DOE to do onsite visit to FE on 8/19 to 8/21 with Doug Wiegmann; did similar visit to MISO the next week.

- Did return visit in Oct

- Many folks played far larger roles; I was only involved extensively early on

Footprints of Reliability Coordinators in Midwest
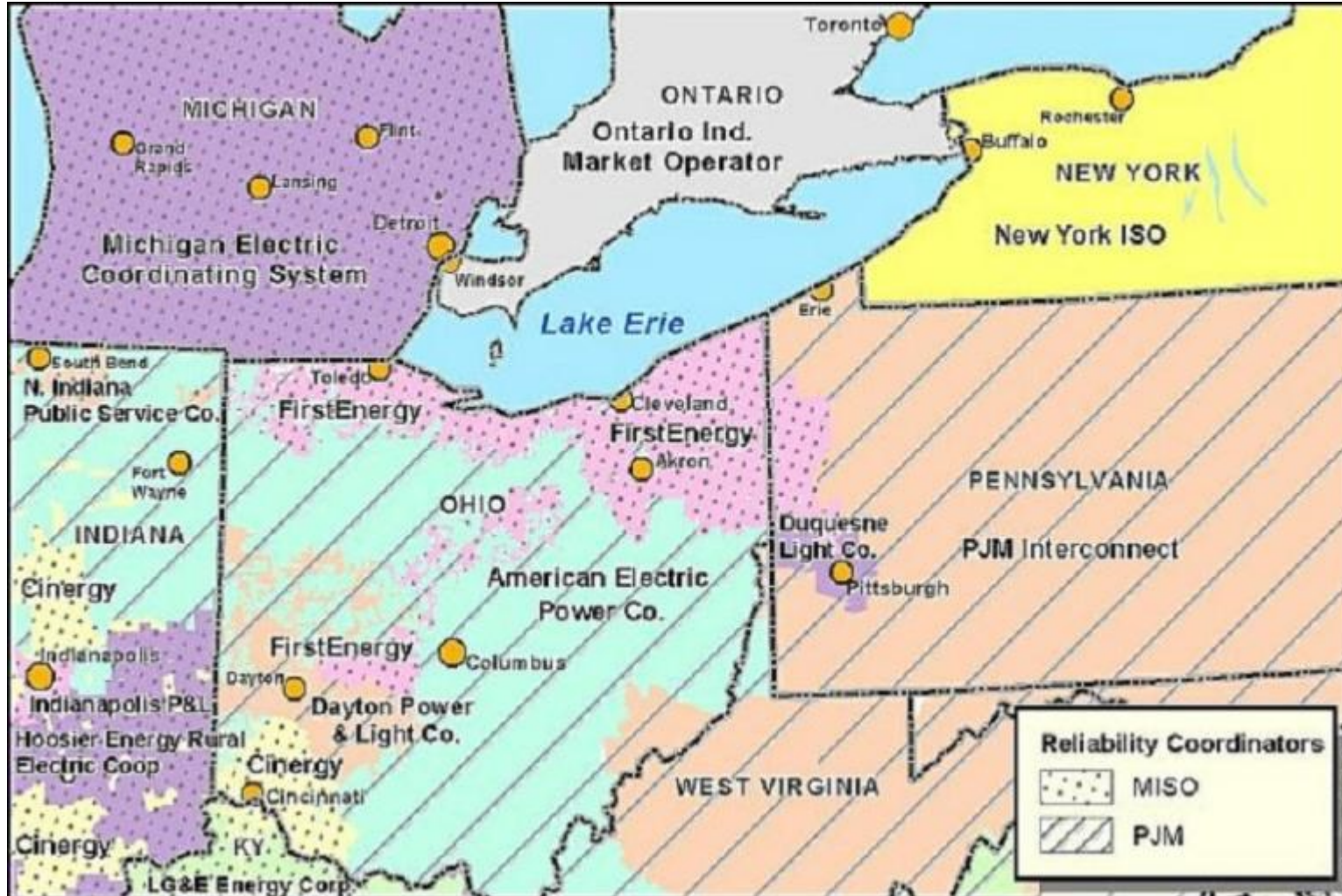
August 13, 2003

- It is important to realize that immediately before the blackout few people thought the system was on the verge of a catastrophe.

- NERC 2003 Summer Assessment did not list Ohio as an area of particular concern

NERC 2003 Summer Assessement is available at http://www.nerc.com/files/summer2003.pdf
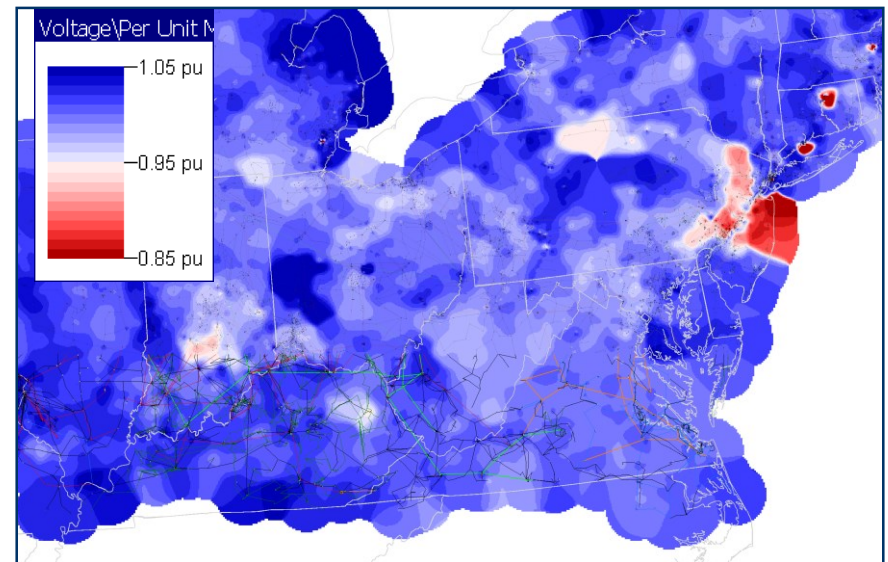
August 14, 2003: Pre-blackout (before 14:30 EDT)

- It had mostly been a normal summer day at First Energy
  - Most generation was available though the 883 MW Davis-Besse Nuclear unit was on a long-term outage
  - At 13:31 EDT the Eastlake 5 unit (a 597 MW plant on Lake Erie) tripped when the operator tried to up is reactive output, but this was not seen as a severe event
- It had been a busy day at MISO, with their reliability coordinators dealing with a relatively small outage in Indiana around noon
  - Their state estimator failed at 1215 EDT but no one know this

Cinergy Bedford-Columbus 345 kV Line Tree Contact at 12:08 EDT

Trees were Finally "Trimmed" Two Months Later

At 14:27 EDT Star-South Canton 345 kV Line Trips and Recloses

- Star-South Canton is a tie between AEP & FE

- FE missed seeing this event since their alarms had hung several minutes earlier (14:14)
  - Line was back in service so it appeared normal in SCADA
  - FE IT folks knew about computer problems

- AEP called FE at 14:32 to check on event; FE says they saw nothing. A repeat call by AEP to FE at 15:19 also discusses event indicating ground current was detected.

Estimated High Level Voltage Profile at 15:00 EDT
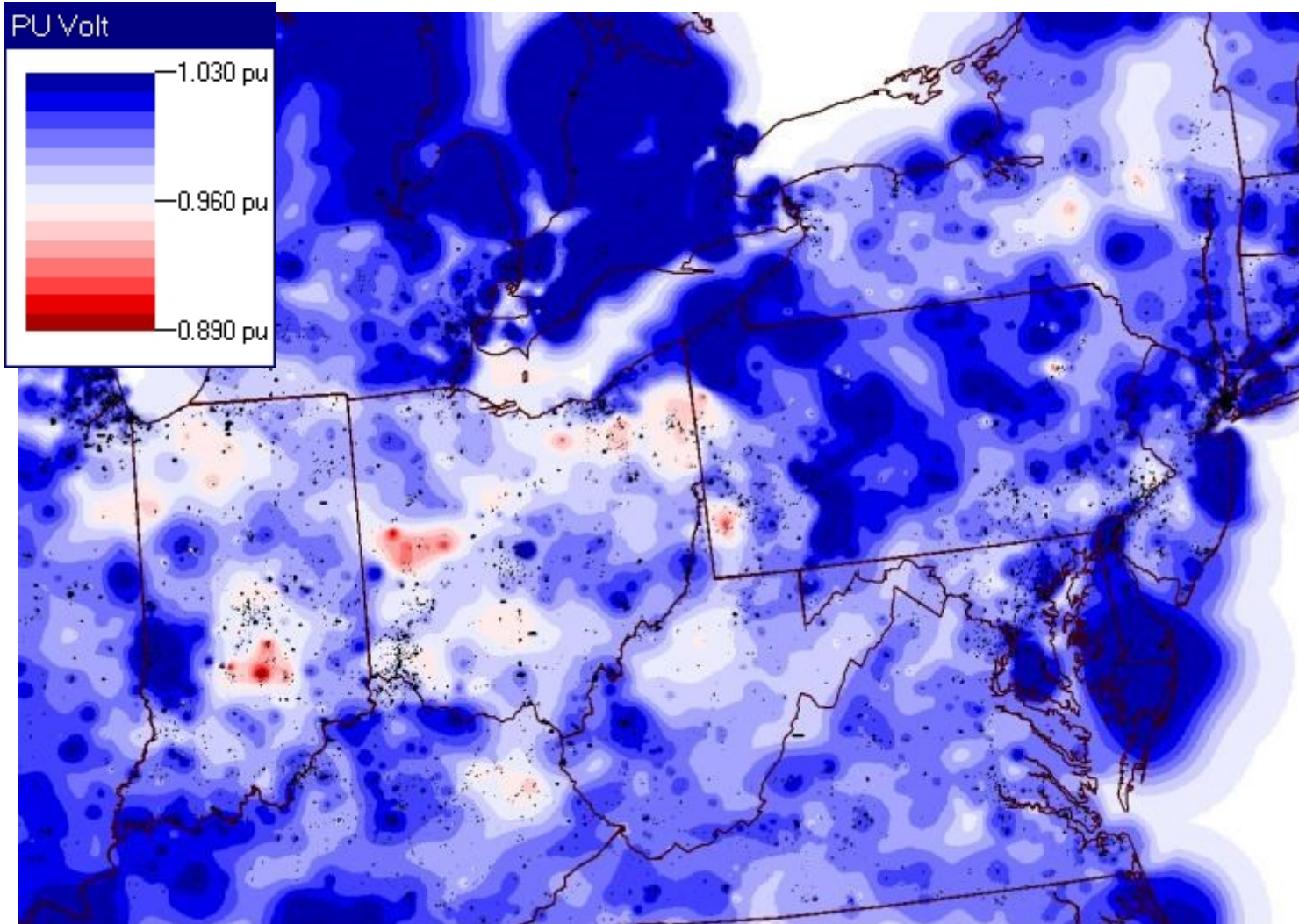
Estimated Flows in Northeast Ohio at 15:00 EDT on August 14th 2003
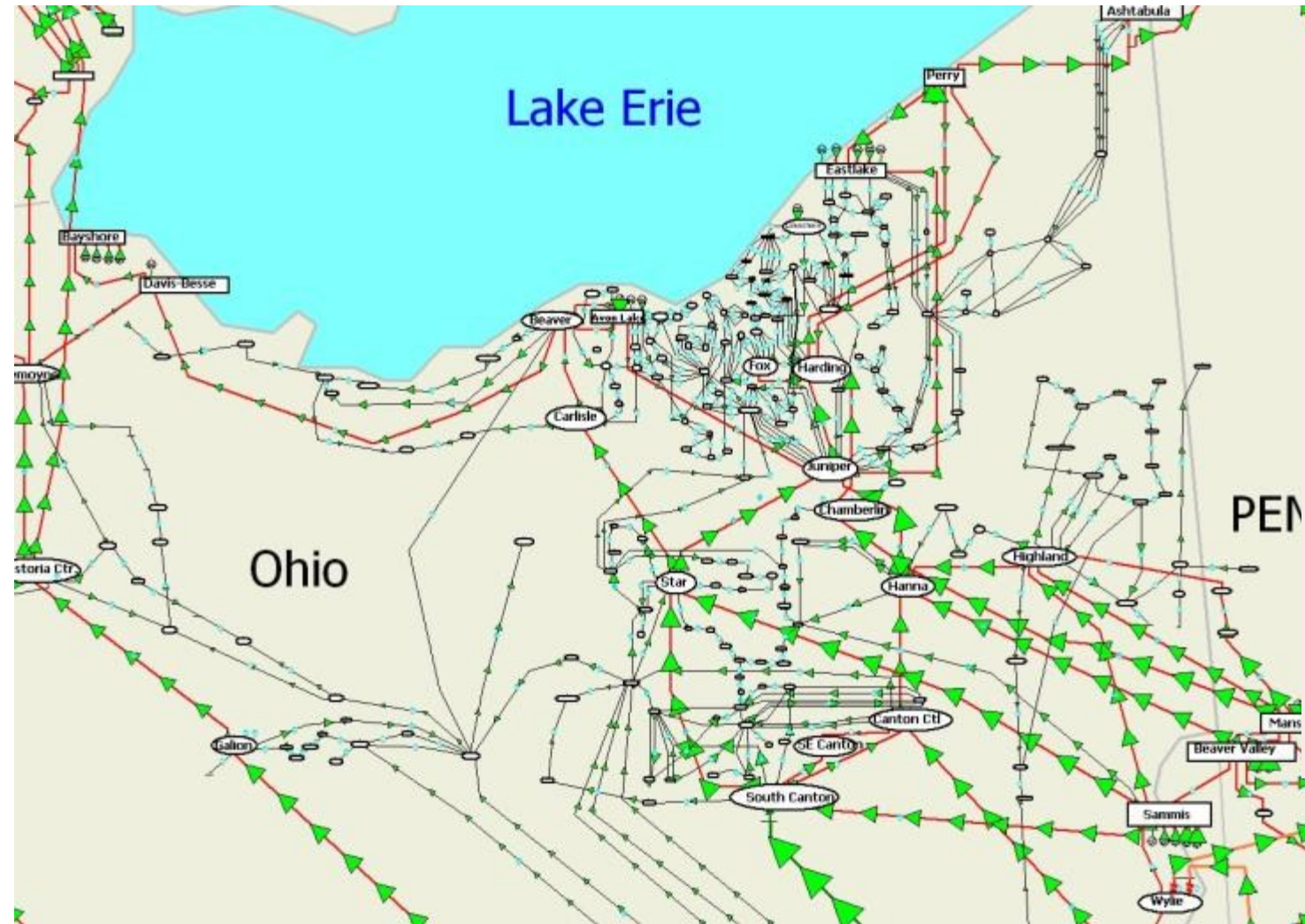
Chamberlin-Harding 345 kV Line trips at 15:05, an event that was missed by both FE and MISO

Chamberlin-Harding was NOT on the ECAR Map (but was on FE's Maps)
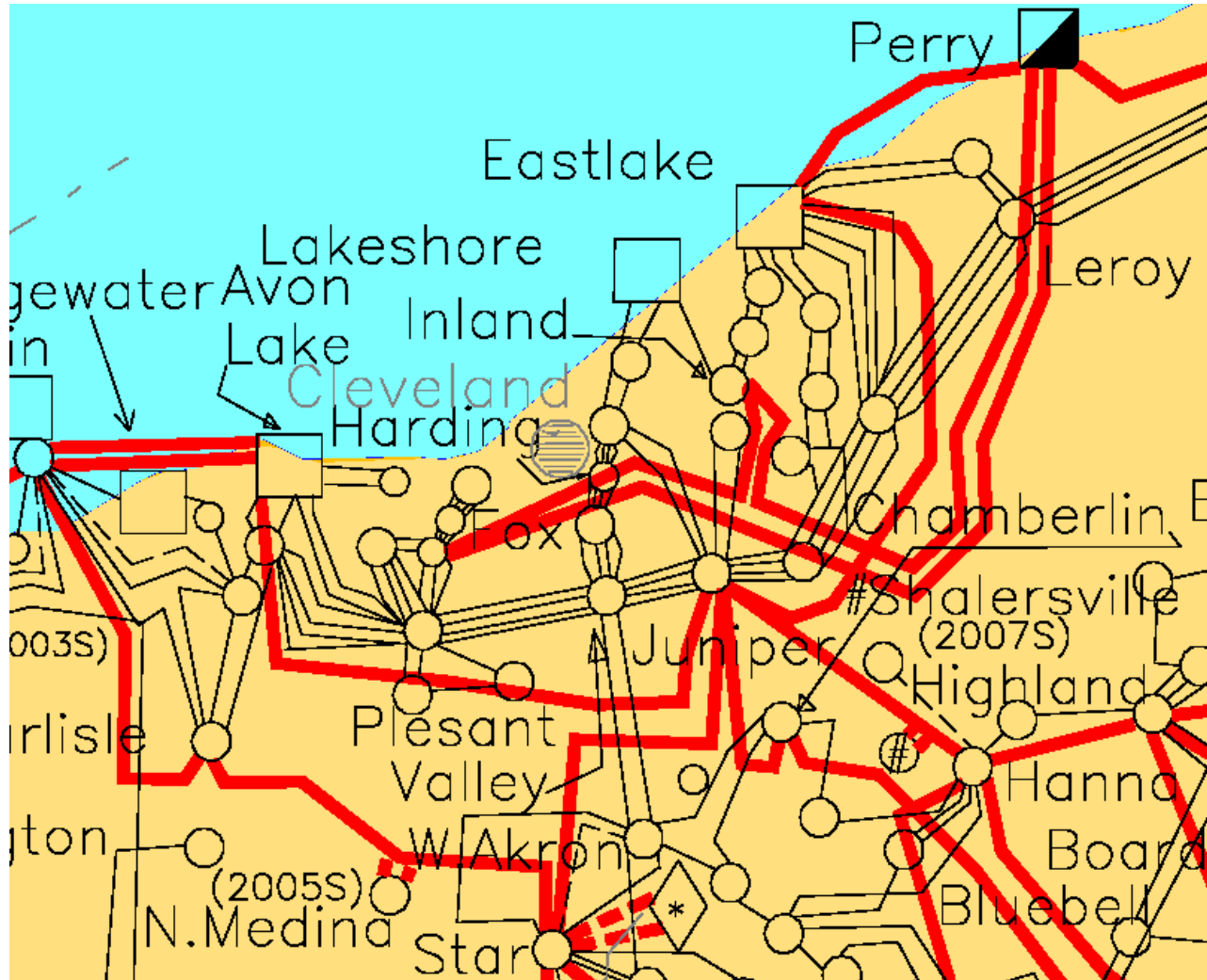
Estimated Flows in Northeast Ohio at 15:06 EDT
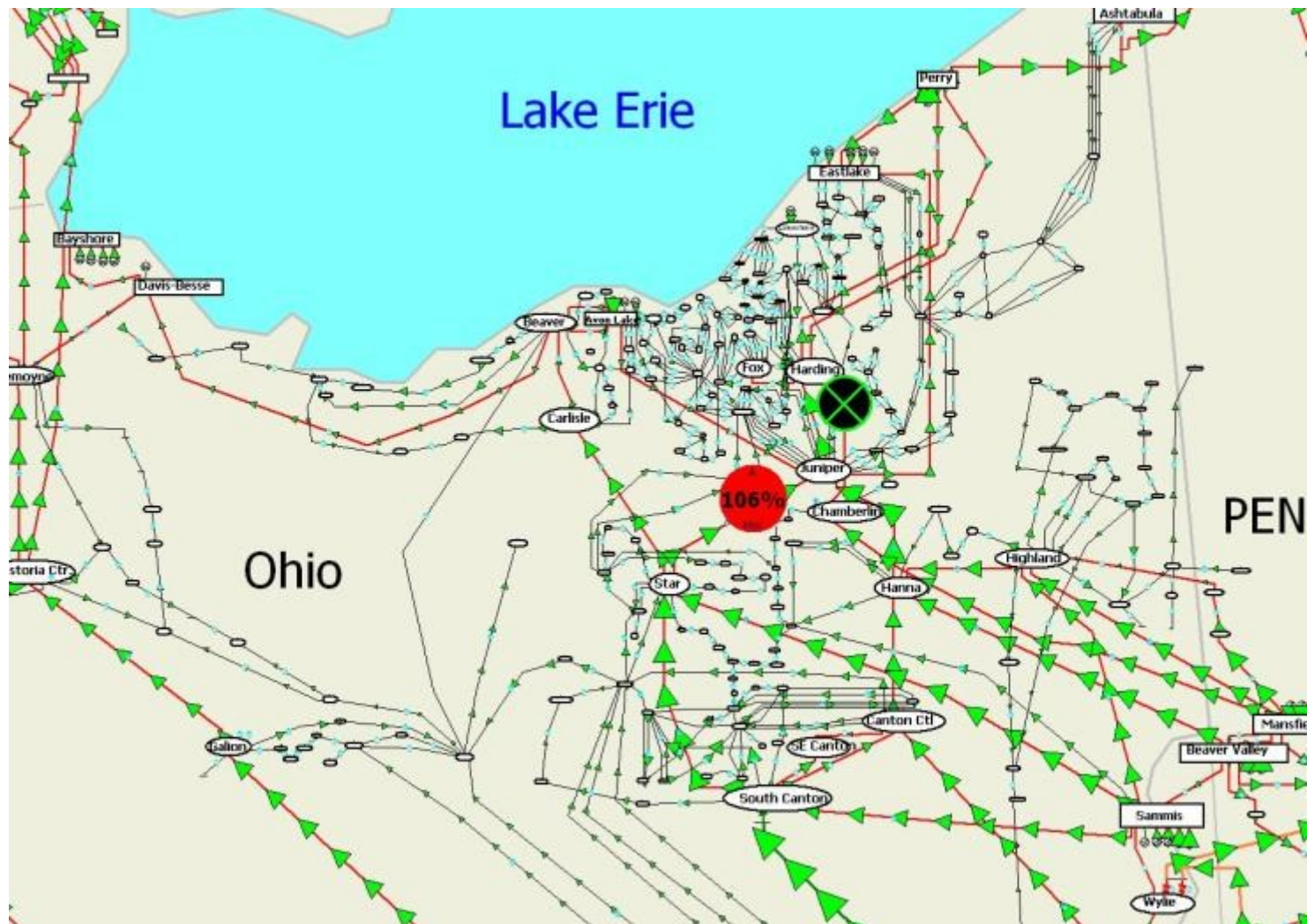
Line Outage Distribution Factors (LODFs)

- LODFs are used to approximate the change in the flow on one line caused by the outage of a second line

  - typically they are only used to determine the change in the MW flow

  - LODFs are used extensively in real-time operations

  - LODFs are state-independent (calculated using dc power flow approximations) but do dependent on the assumed network topology

  - Below value tells change of real power flow on line ℓ for the assumed outage of line k; f_k^0 is (obviously) pre-contingent

$$\Delta f_\ell = d_\ell \qquad f^0$$

Flowgates

- The real-time loading of the power grid is accessed via "flowgates"

- A flowgate "flow" is the real power flow on one or more transmission element for either base case conditions or a single contingency

  - contingent flows are determined using LODFs

- Flowgates are used as proxies for other types of limits, such as voltage or stability limits

- Flowgates are calculated using a spreadsheet

Flowgate #2265

- Flowgate 2265 monitors the flow on FE's Star-Juniper 345 kV line for contingent loss of the Hanna-Juniper 345 Line
  - normally the LODF for this flowgate is 0.361
  - flowgate has a limit of 1080 MW
  - at 15:05 EDT the flow as 517 MW on Star-Juniper, 1004 MW on Hanna-Juniper, giving a flowgate value of 520+0.361*1007=884 (82%)
  - Chamberlin-Harding 345 opened at 15:05; FE and MISO all missed seeing this

The Bad LODF that Maybe Blacked Out the Northeast

- At 15:06 EDT (after loss of Chamberlin-Harding 345) #2265 has an incorrect value because its LODF was not automatically updated.

  – Value should be 633+0.463*1174=1176 (109%)

  – Value was 633 + 0.361*1174=1057 (98%)

- At 15:32 the flowgate's contingent line opened, causing the flowgate to again show the correct value, about 107%

Flows at 15:33 EDT
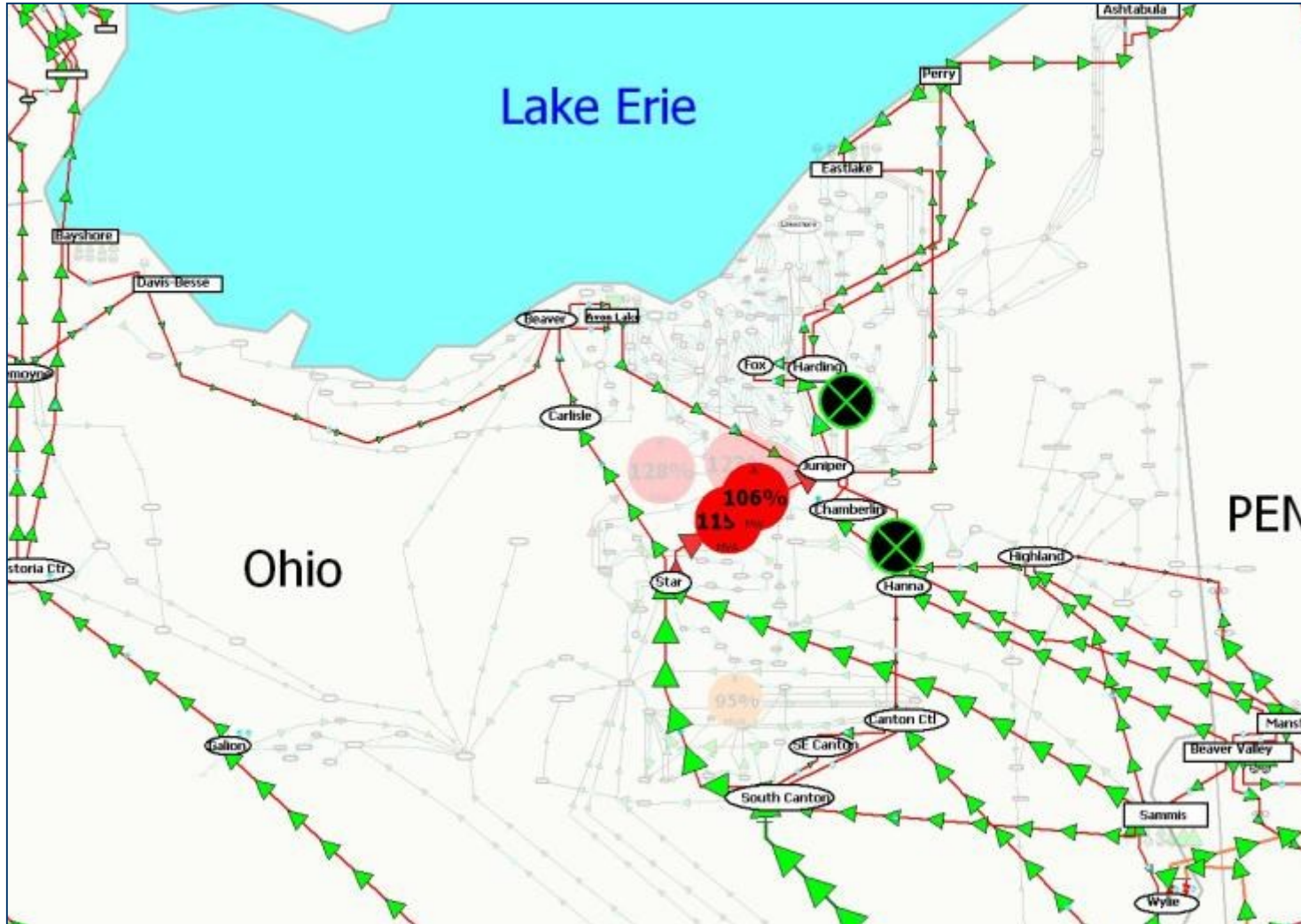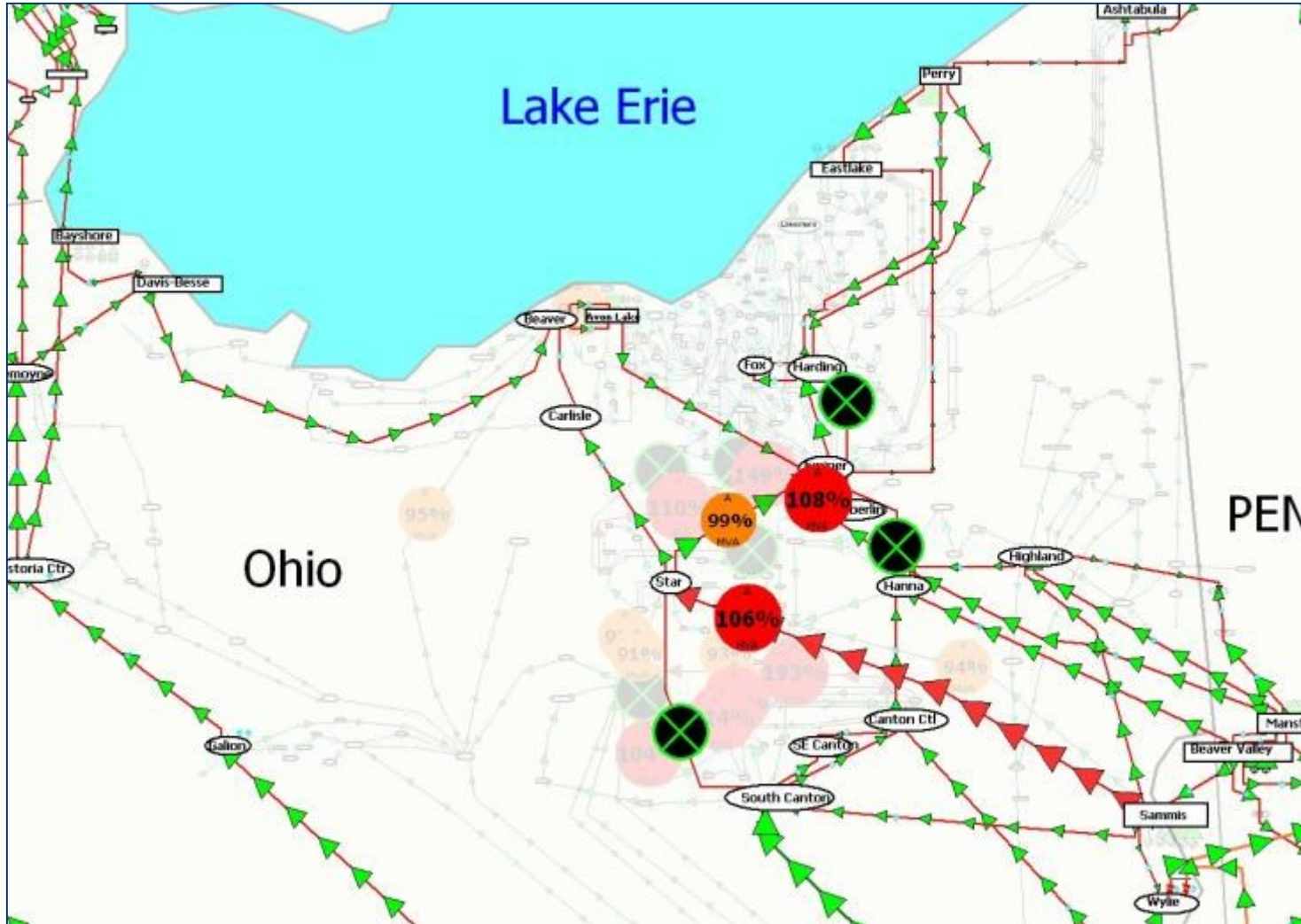
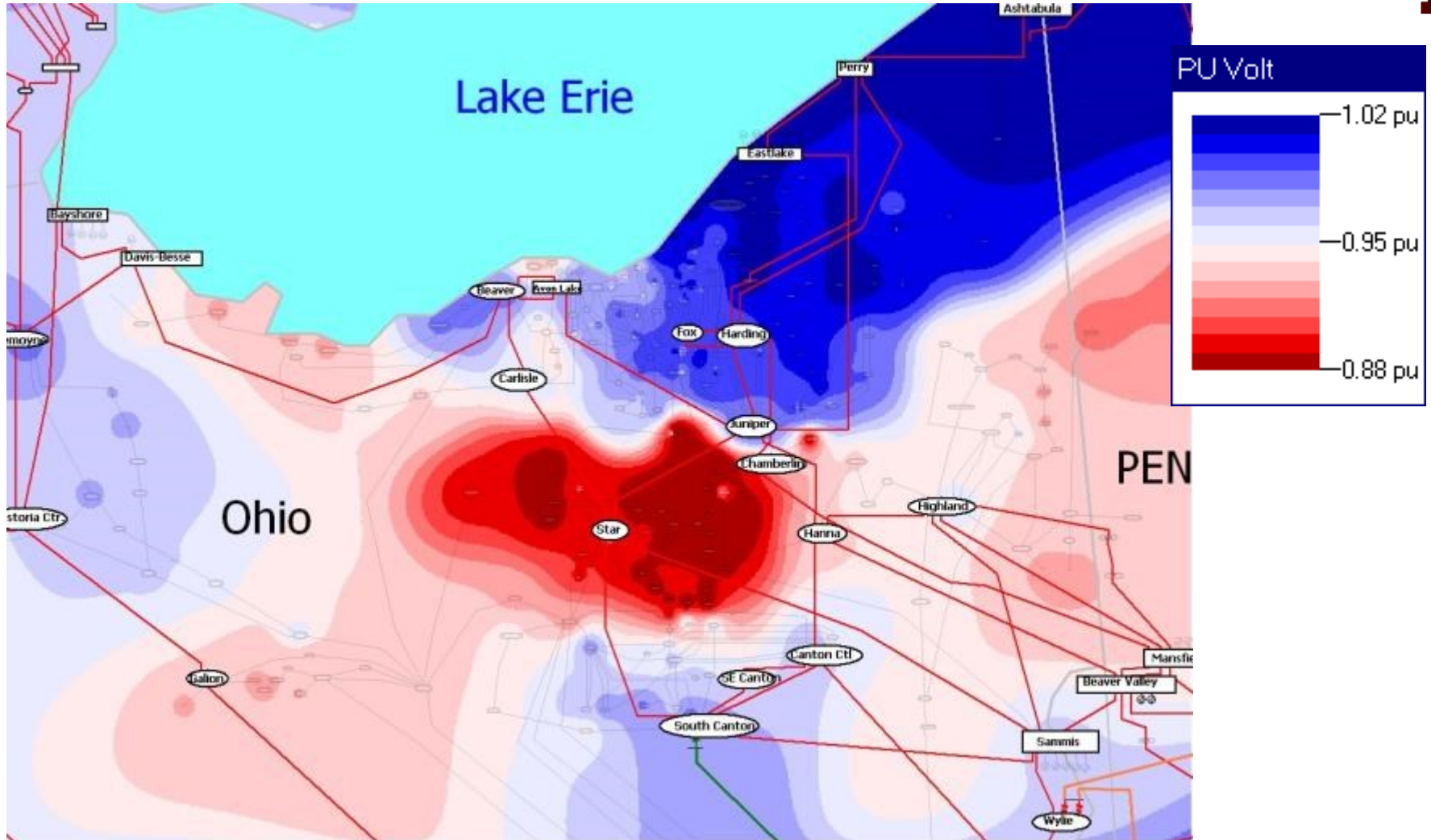# Estimated Northeast Ohio 138 kV Voltage Contour: 15:33 EDT
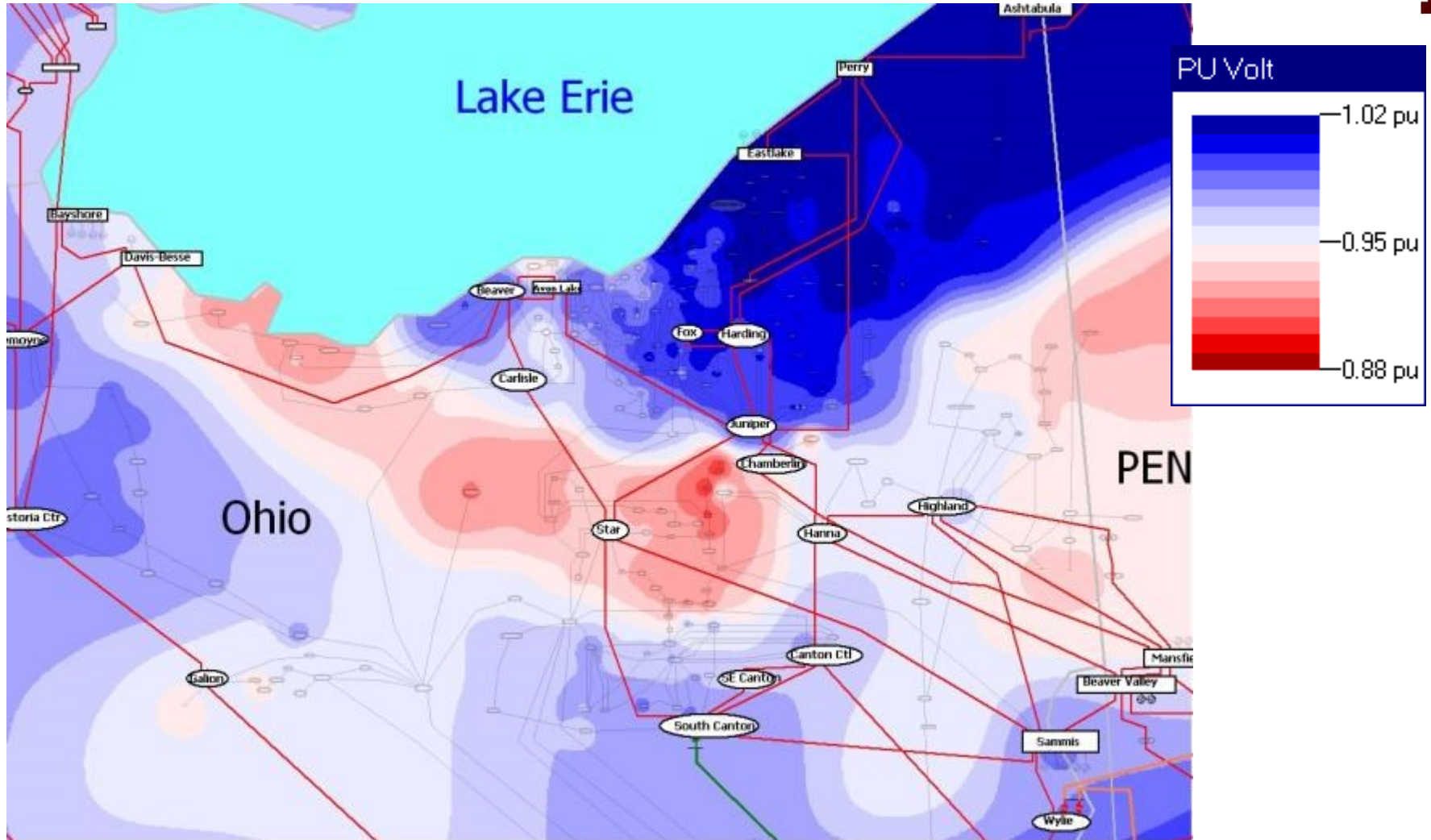
IT Issues

- MISO RCs had gotten many hundreds of "alarms"

- Contingency analysis results were giving pages of violations.

- SE would fail because of severe system stress

- Inadequate procedures for dealing with SE failure.

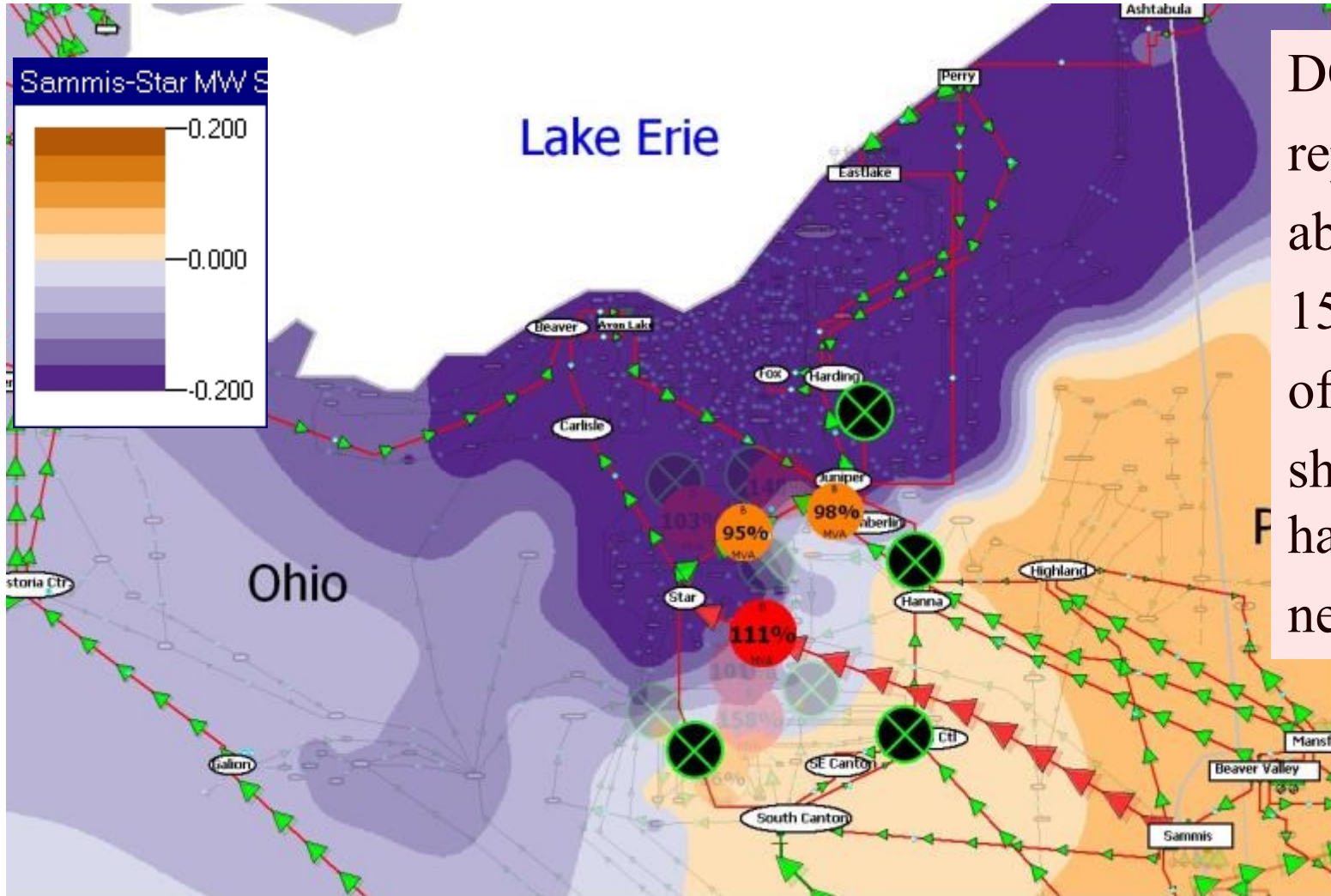- FE control center would get "many phone calls;" information was not effectively shared.

Estimated Flows in Northeast Ohio at 15:46 EDT on August 14th 2003
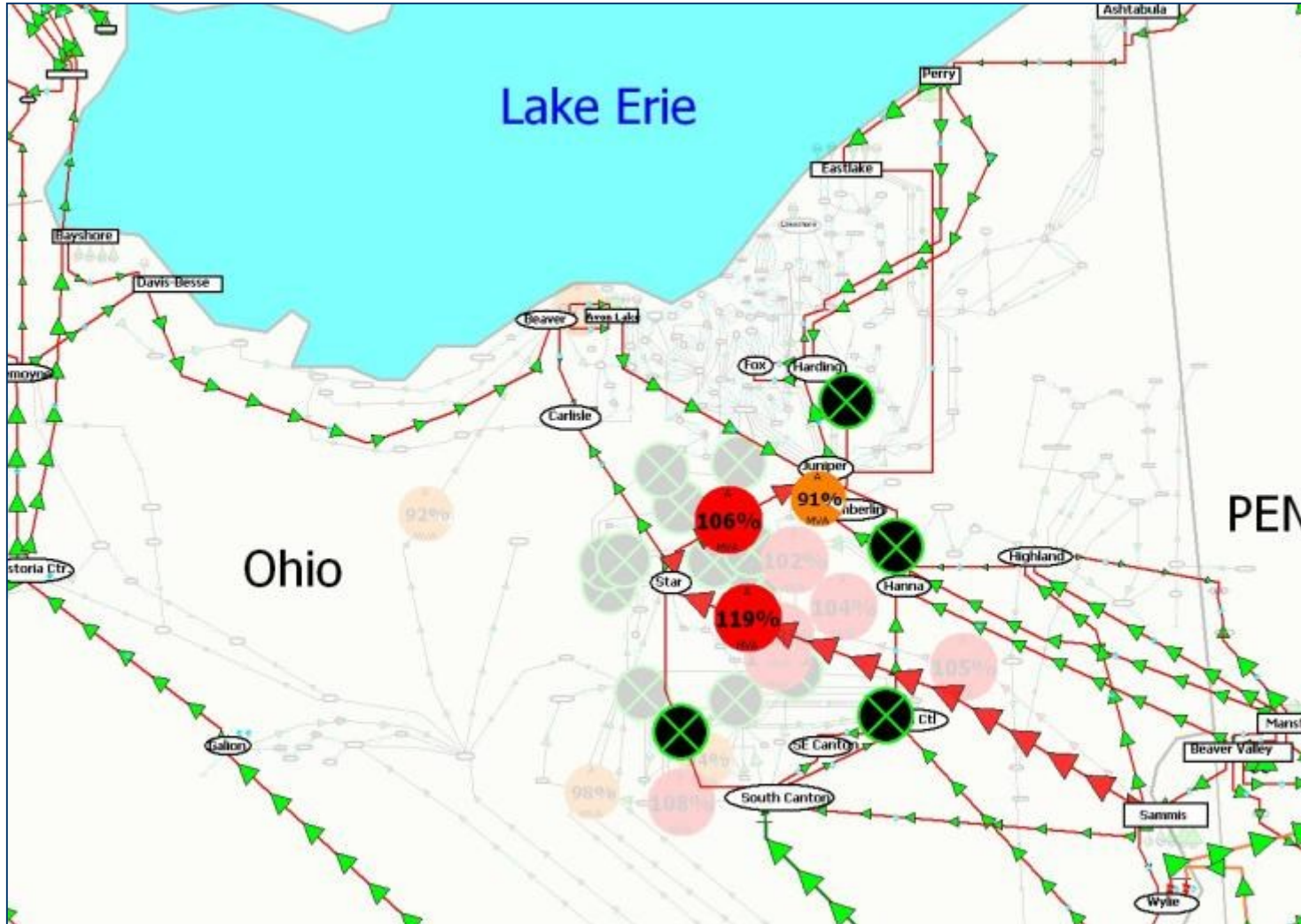
Estimated Northeast Ohio 138 kV Voltage Contour: 15:46 EDT

What Could Have Been Done?
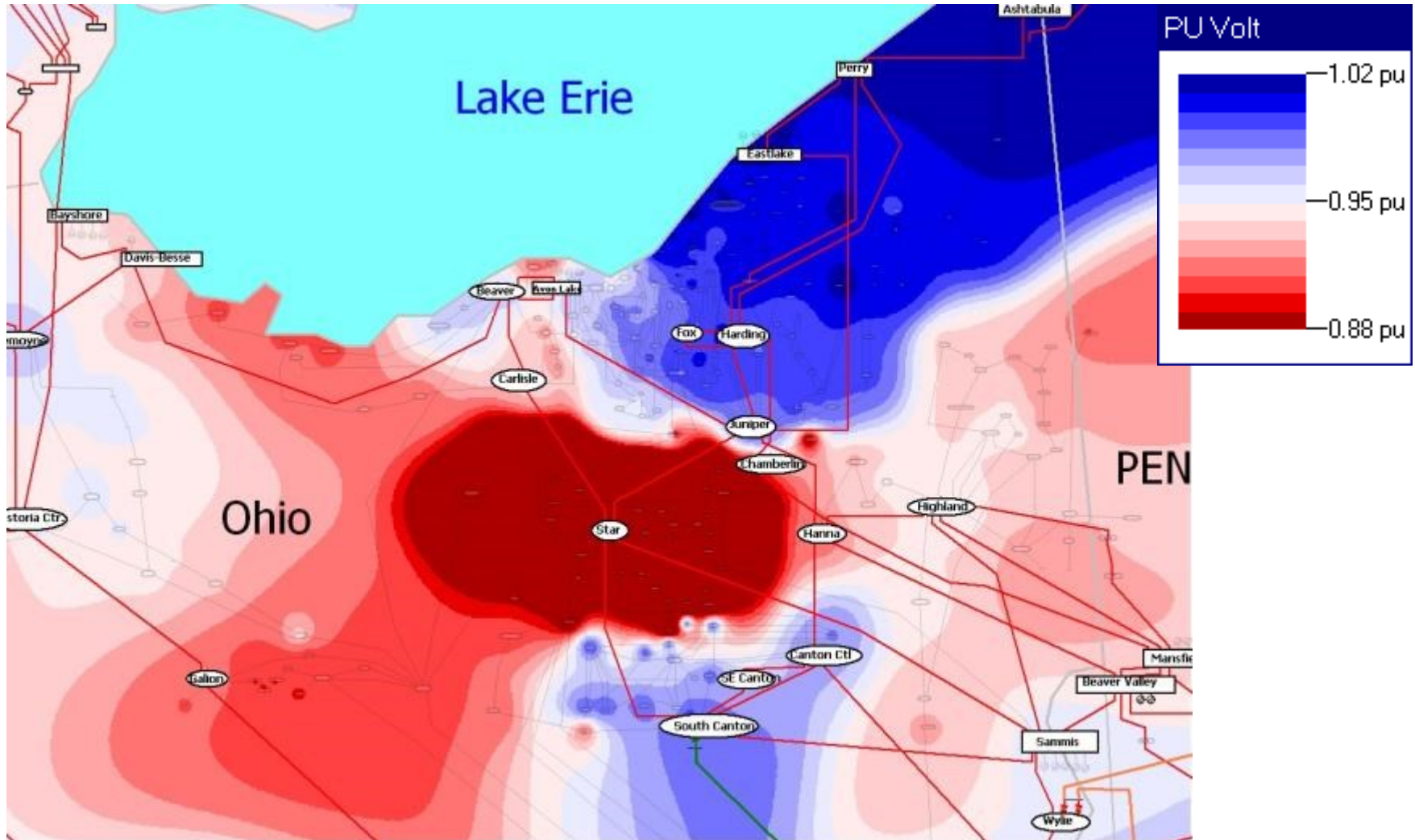## Sammis-Star Flow Sensitivities

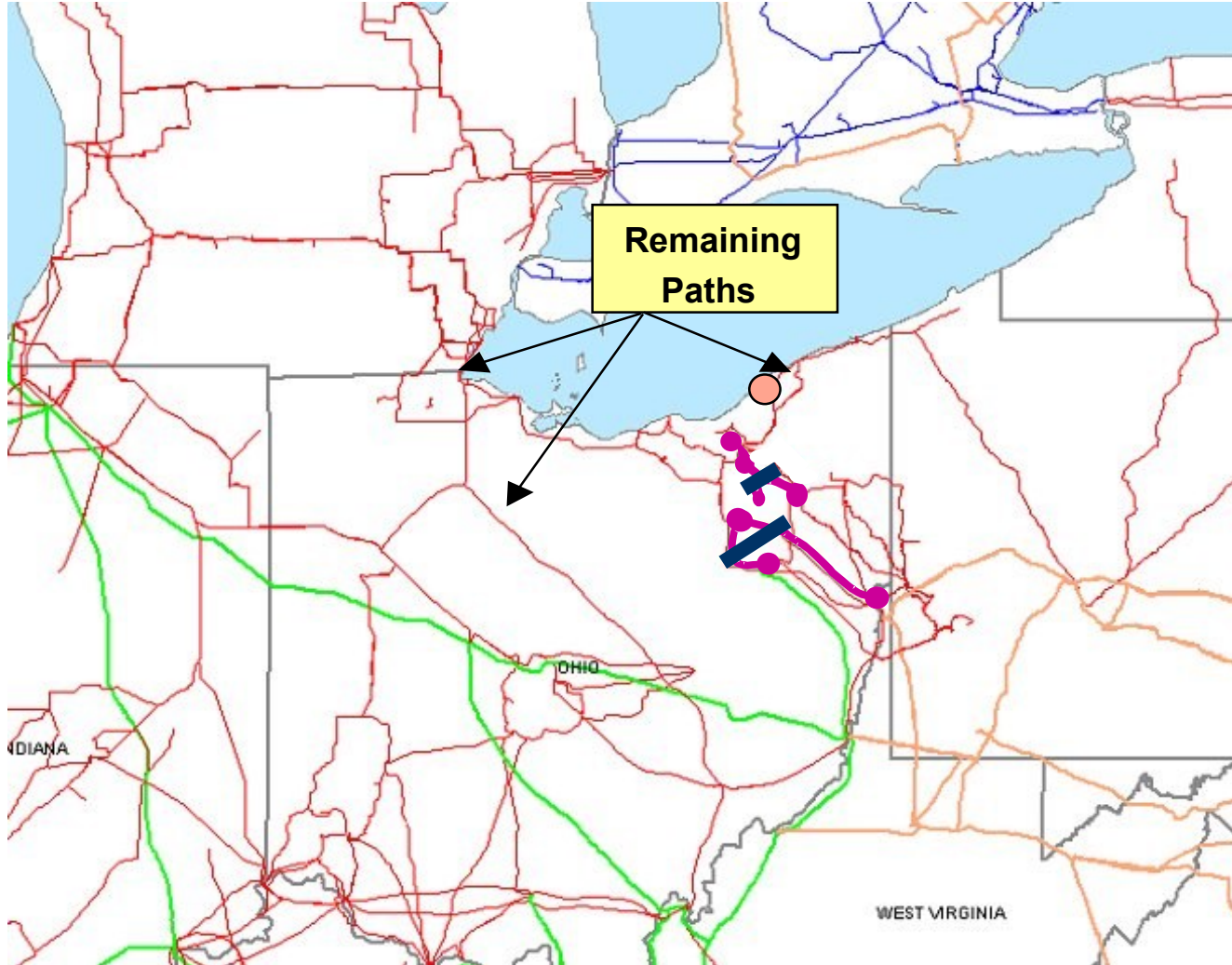DOE/NERC report said about 1500 MW of load shed would have been needed

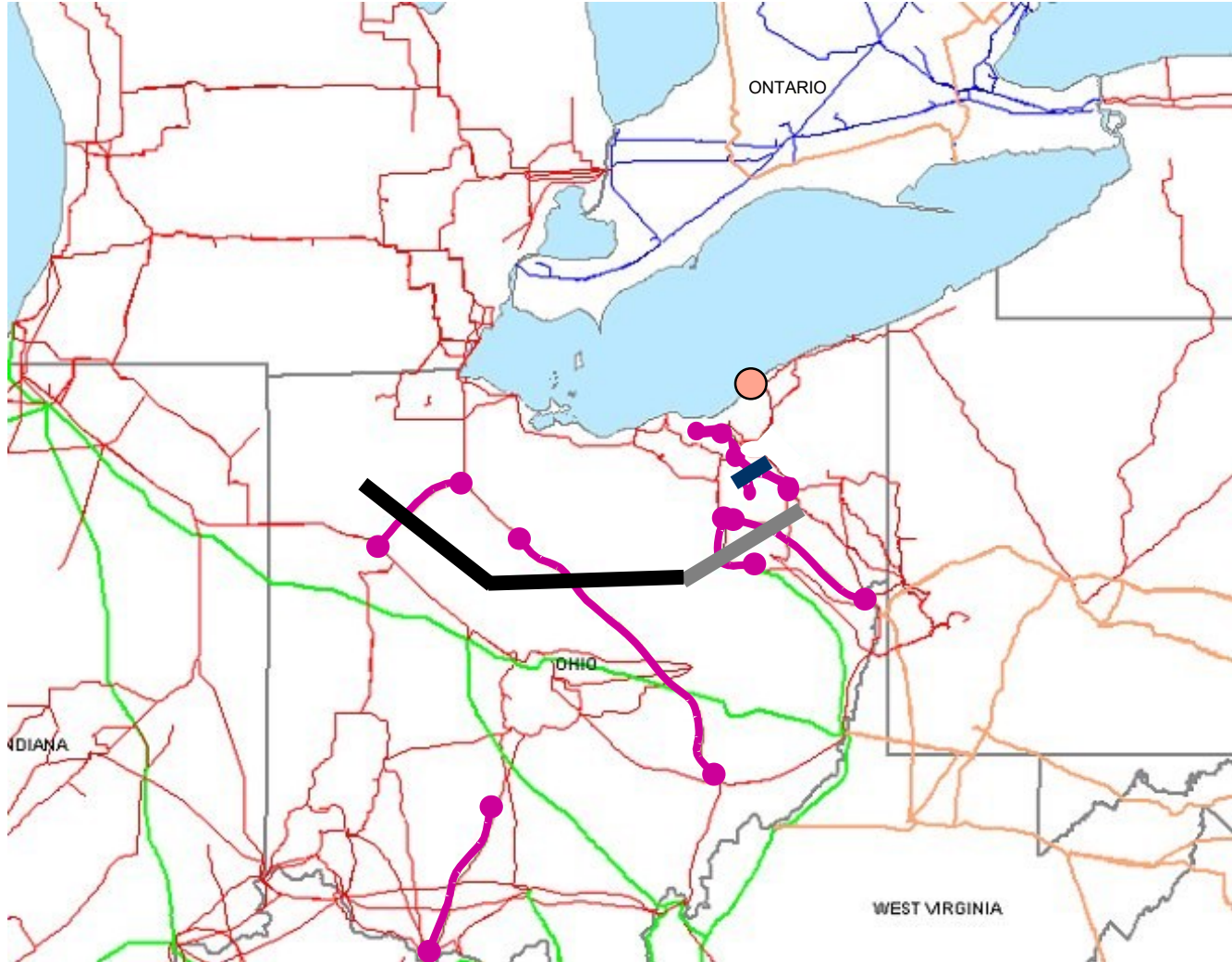# Estimated Flows in Northeast Ohio at 16:05 EDT on August 14th 2003

Estimated Northeast Ohio 138 kV Voltage Contour: 16:05 EDT

Remaining Paths

Image Source: August 14 2003 Blackout Final Report

Generation Trips 16:09:08 – 16:10:27
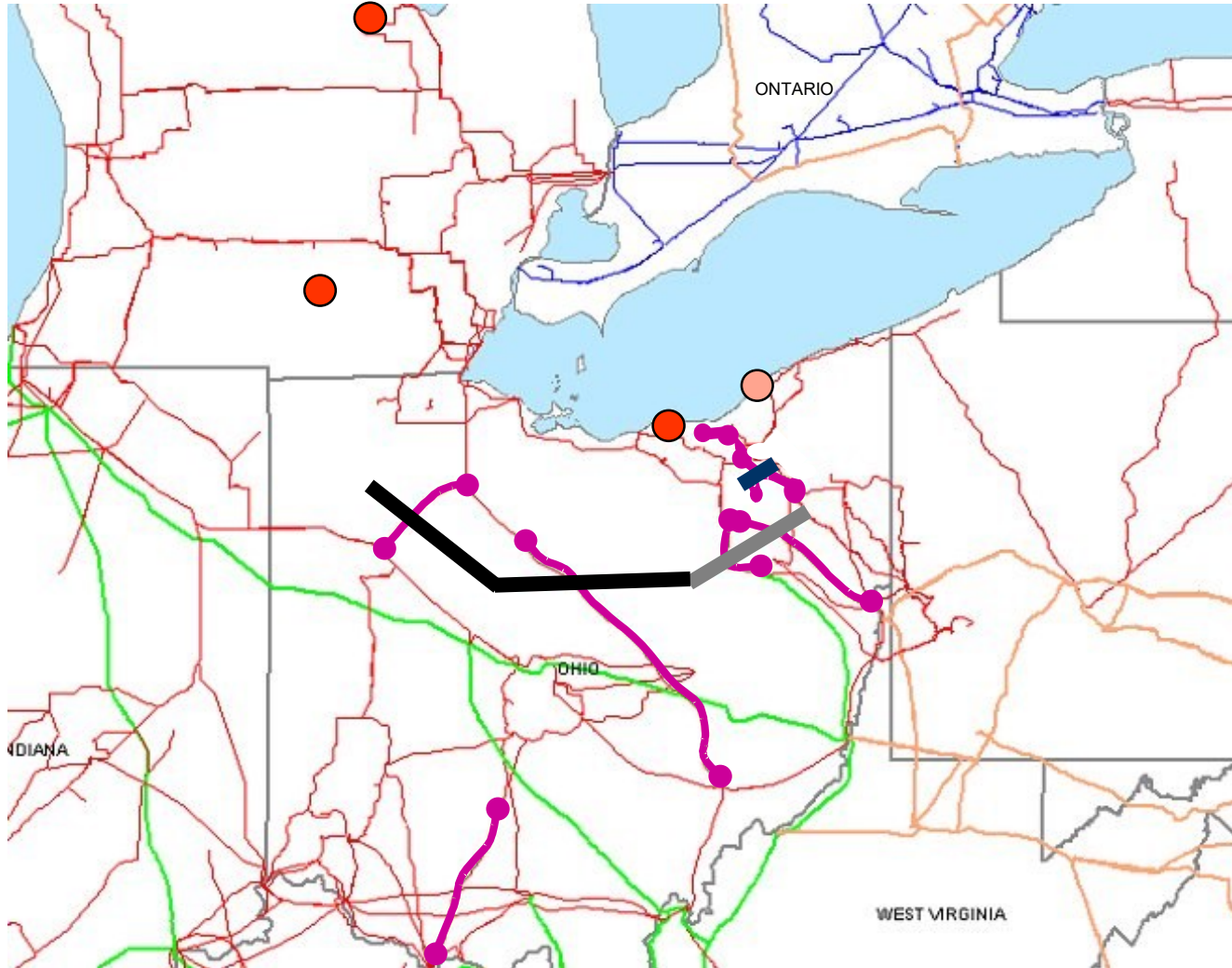
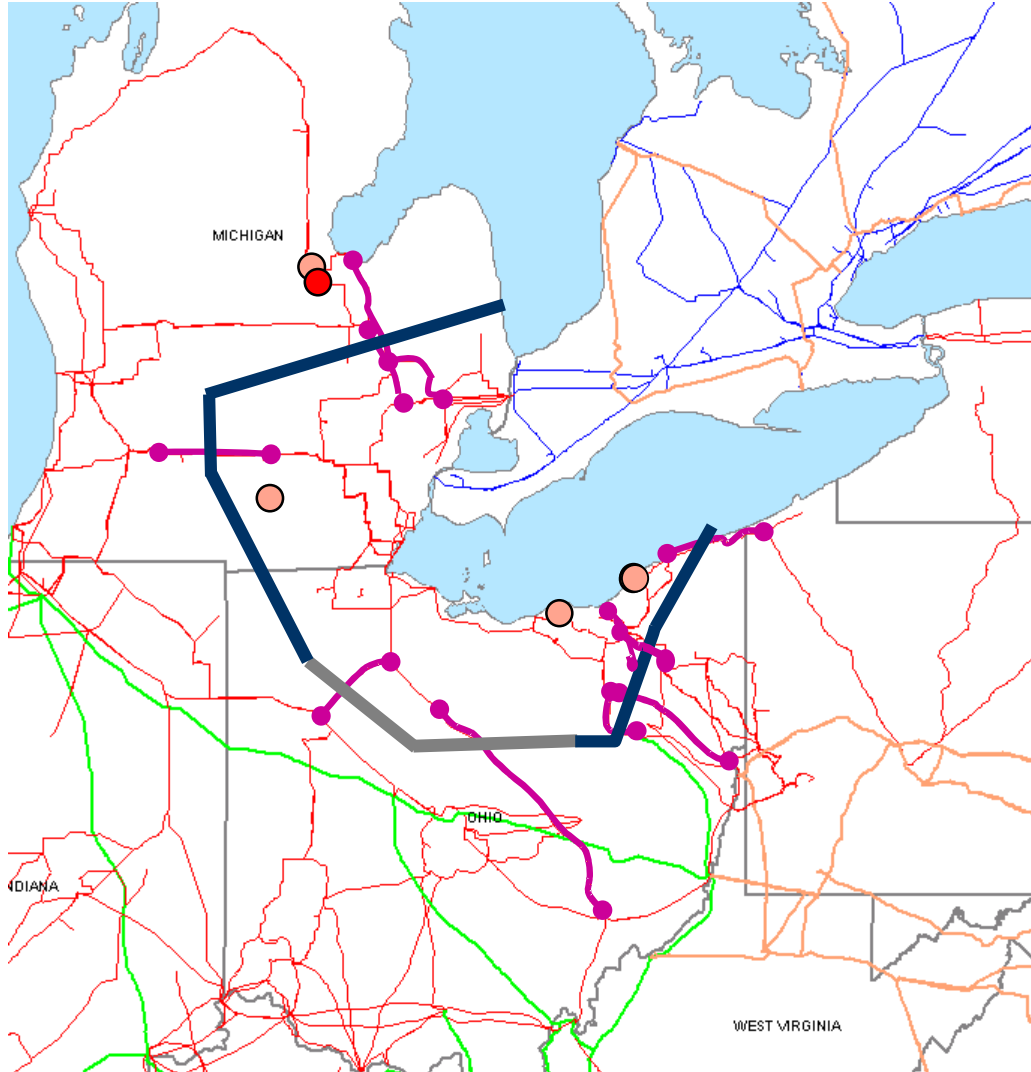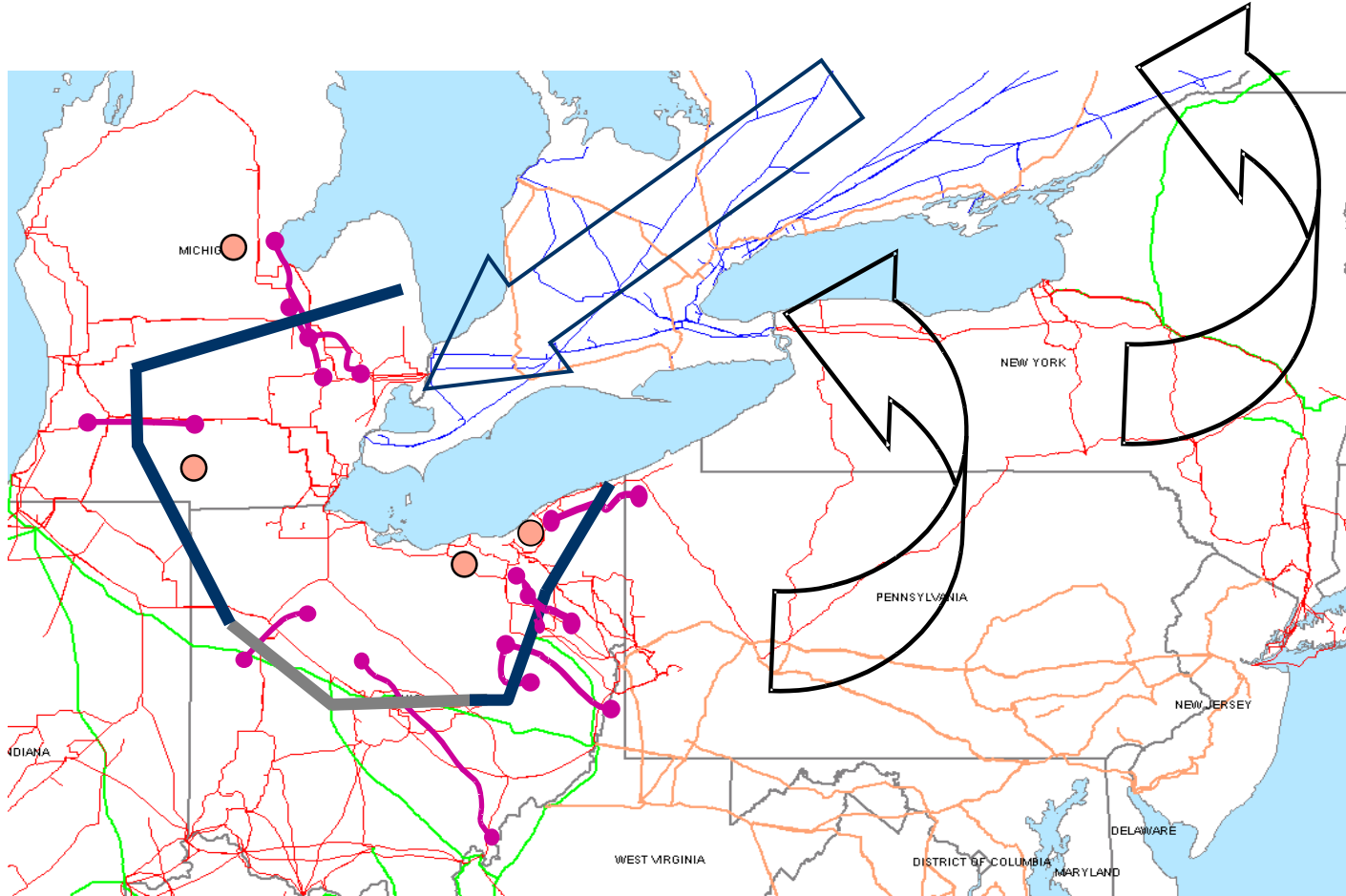Image Source: August 14 2003 Blackout Final Report

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Image Source: August 14 2003 Blackout Final Report

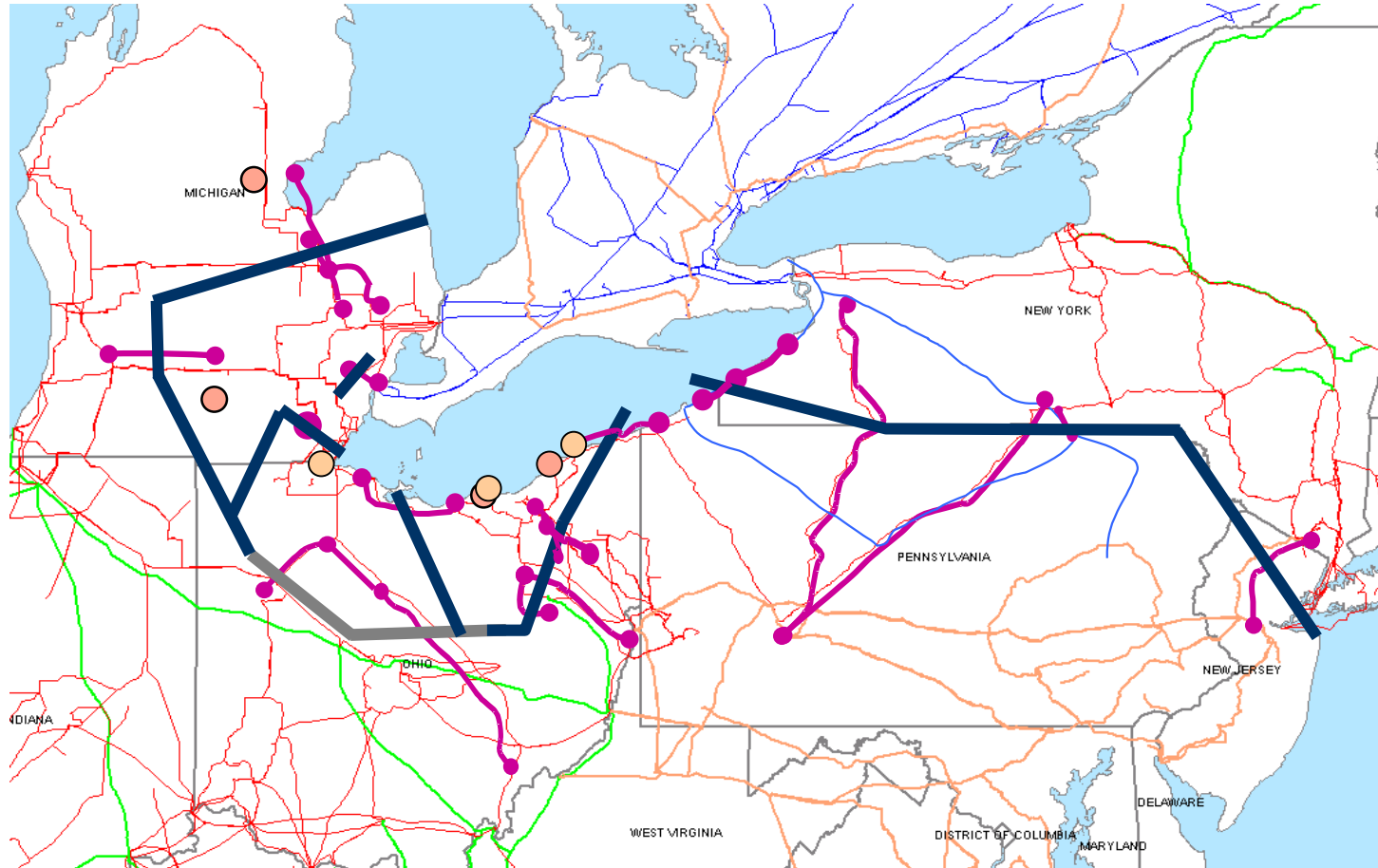# Major Power Reversal: 16:10:38

Ontario/Michigan Interface Flows and Voltage

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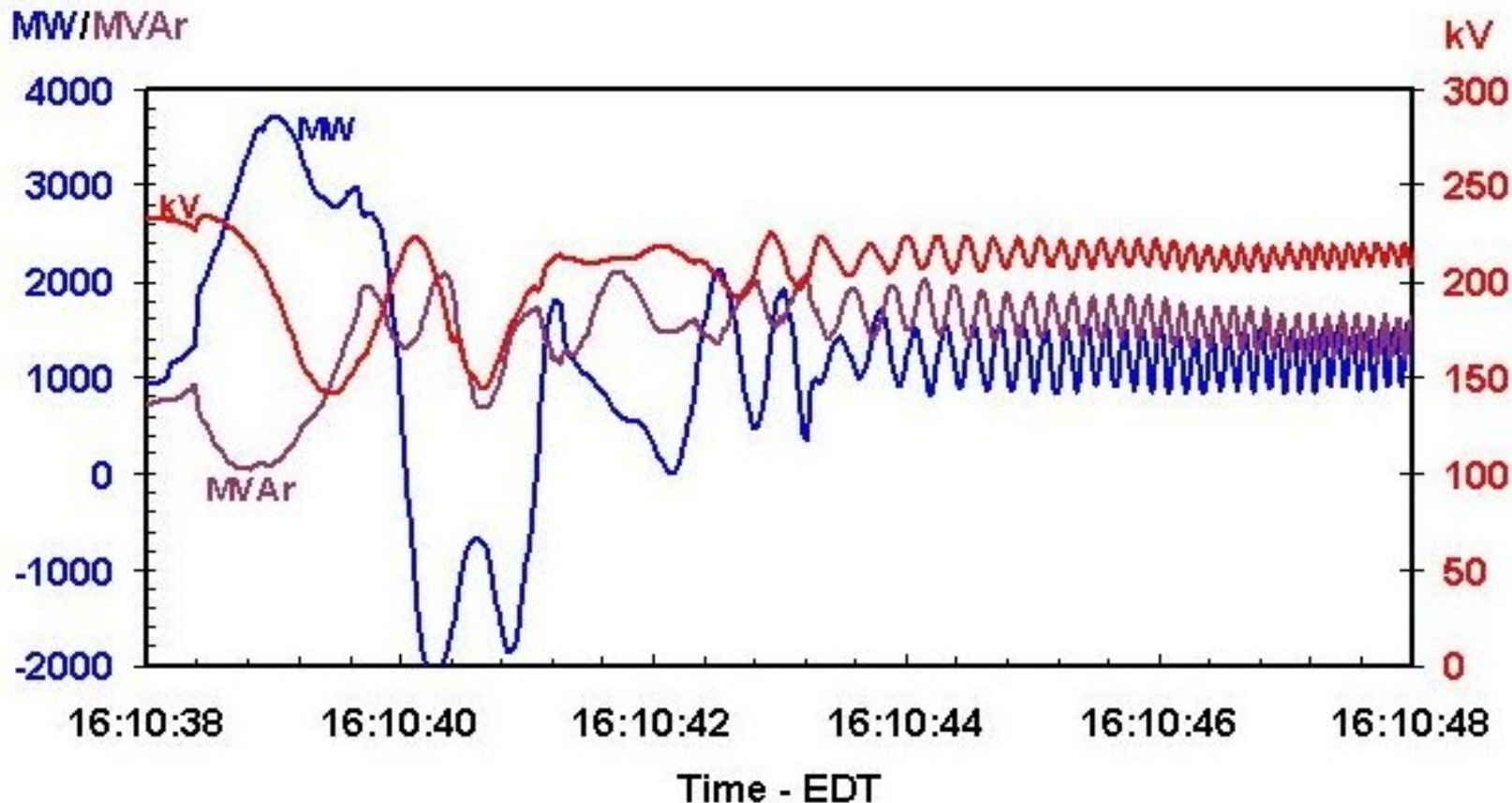
Ties from PJM to New York Open: 16:10:44 (North Ohio Black)

Image Source: August 14 2003 Blackout Final Report

System Islands Break Up and Collapse: 16:10-16:13

Some Local Load Interrupted

Areas Affected by the Blackout
Service maintained
in some area

Image Source: August 14 2003 Blackout Final Report
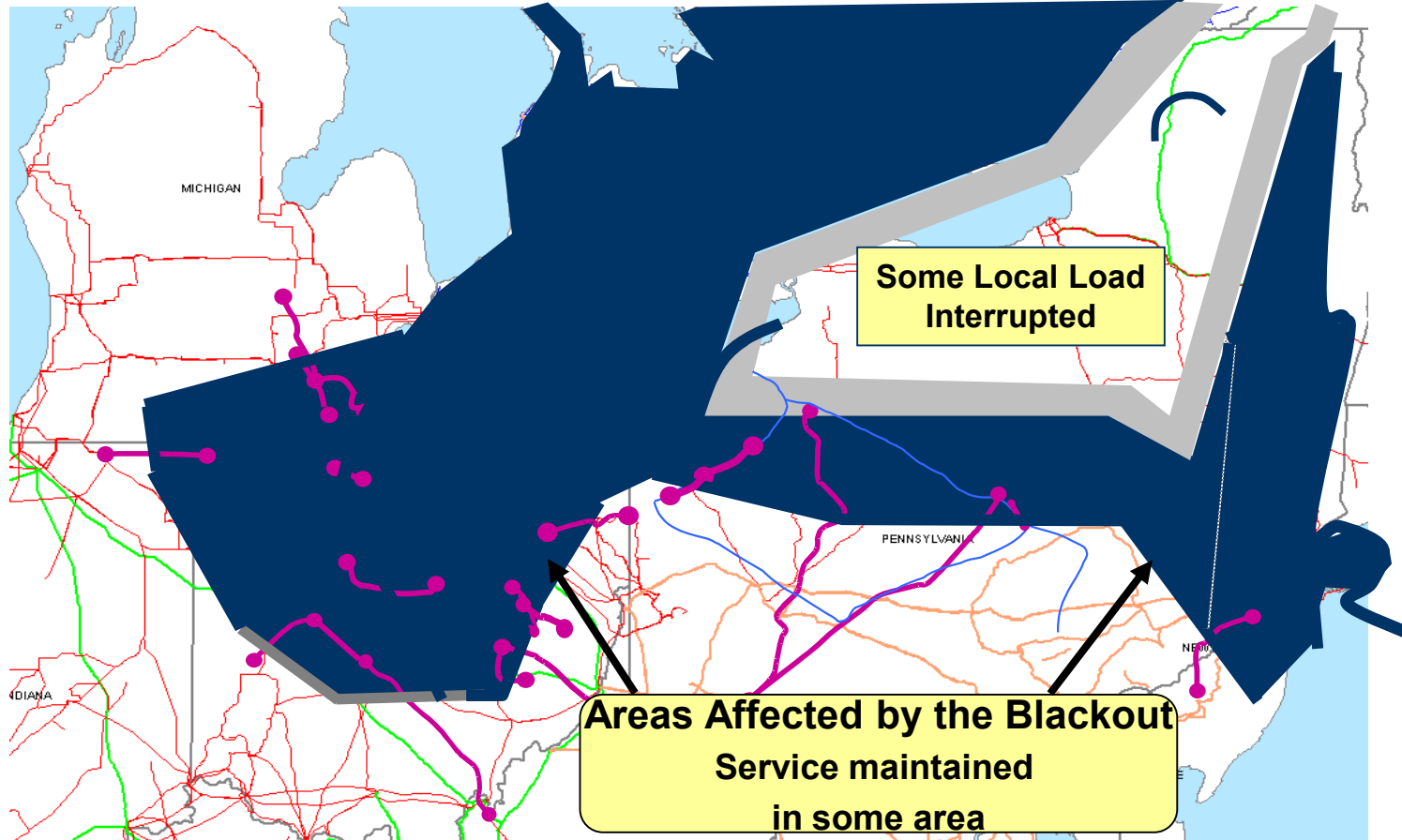
Are DC LODFs Accurate?
August 14th Crash Test

- Here are some results from August 14th

Time	Contingency	Element	LODF	ΔMW (pred)	ΔMW (act)
15:05	Chamberlin-Harding 345	Hanna-Juniper 345	0.362	179	176
15:32	Hanna-Juniper 345	Star-Juniper 345	0.465	545	527
15:46	CantonCentral-Cloverdale 138	Sammis-Star 345	0.164	48	54
15:46	same	Cloverdale-Star 138	0.234	68	64
16:06	Sammis-Star 345 Star-Urban 138 W.Canton-Dale 138	Star-Juniper 345	numerous	517	676
16:06	same	Ashtabula-Perry 345	numerous	319	408

The Results are Actually Quite Good!

- The initial LODF values were accurate to within a few percent

- Even after more than a dozen contingencies, with many voltages well below 0.9 pu, the purely DC LODF analysis was giving fairly good (with 25%) results

What Could Have Occurred on August 14th?

- With 20/20 Hindsight the blackout probably could have been prevented. A smarter grid might have provided the necessary situational awareness, and/or provided the dynamic load reduction necessary to keep the system from cascading.

- But key issues are 1) which grid improvement costs are cost justified, and 2) what are we missing?

How Could a Smart Grid Help?

- Under frequency and under voltage relays can provide quick reduction in the load, but they need to be smart enough to make the right decision

- Dynamic pricing (LMPs) can help customers make economic decisions, but they depend upon a variety of "advanced applications" in order to calculate the LMPs: state estimation converging to provide the model for the SCOPF

Some Thoughts on Current Needs

- The data used in the models for interconnect wide studies still have significant problems

- In US we have 100 GW of wind resources, but do not always have adequate models for transient stability studies; there are also potential low voltage ride through issues with solar

- Power grid is rapidly changing which can result in some operational "surprises"

- High impact, low frequency events are also a concern

- We need people with a deep knowledge of power systems and (fill in the blank)!