ECEN 460
Power System Operation and Control
Spring 2025

Lecture 14: August 14, 2003 Blackout and Winter Storm Uri

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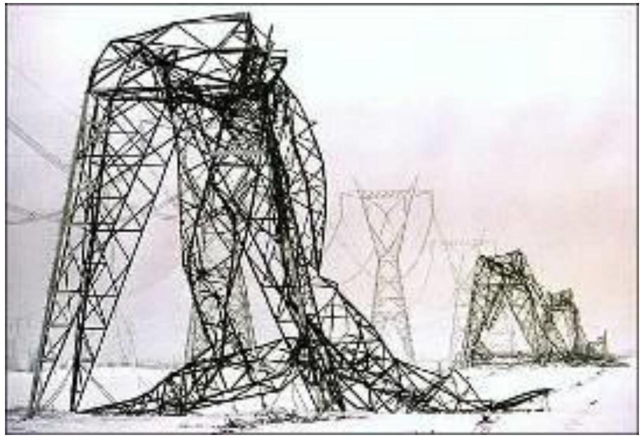
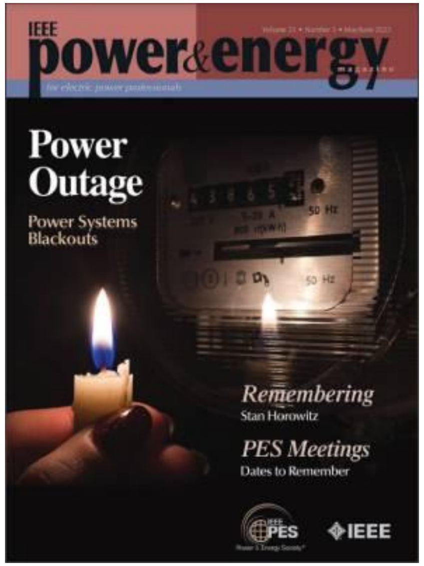
TEXAS A&M UNIVERSITY

Blackouts and Restoration

- Modern society depends on a reliable electric grid.
- Blackouts are costly, with some estimates of costs above $100 billion/year in the US.
- Blackouts can differ substantially in their impact, with most caused by local, lower voltage distribution issues.
- In May/June 2023 Jeff Dagle and I edited a special IEEE Power and Energy Magazine issue on blackouts
  - It is free for IEEE PES members





Upper right image: New York Daily News Archive

Electric Grid Operating States

- The goal of electric grid planning and operations is to prevent blackouts. Still, they do occur, and when they do the focus switches to restoration
- Blackouts come in all different sizes, with the vast majority local issues in the distribution system that can be quickly fixed with resources the utility already has

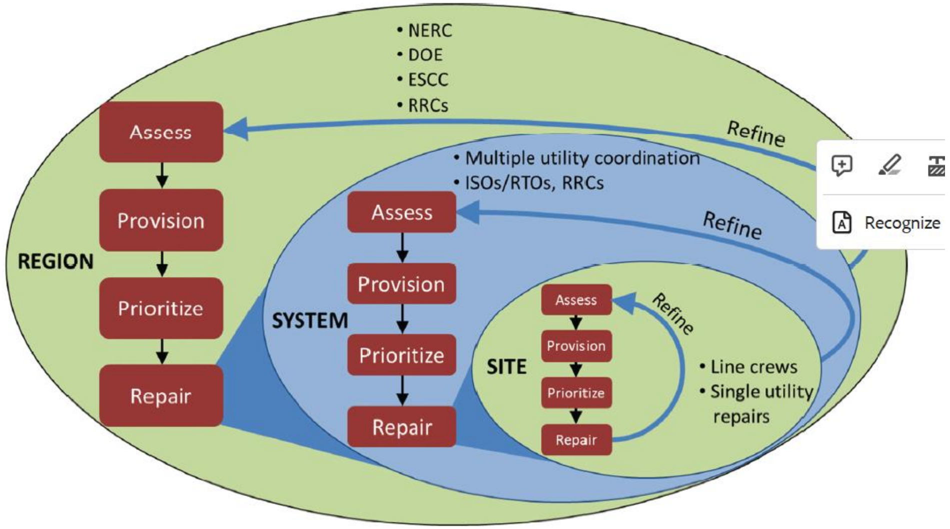


FIGURE 6.1 Illustration of the general processes of restoration that occur on multiple levels by different institutions with responsibility for electricity restoration.
NOTE: NERC, North American Electric Reliability Corporation; DOE, Department of Energy; ESCC, Electricity Subsector Coordinating Council; RRC, Regional reliability coordinator; ISO, Independent system operator; RTO, Regional transmission operator.

- There is a much greater challenge for large-scale blackouts, especially with equipment damage

Image source: US National Academies 2017, Enhancing Resilience of US Electric Grid Report

The Real Cause of Most Blackouts!

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

Most outages occur in the distribution system, and many of those are caused by animals

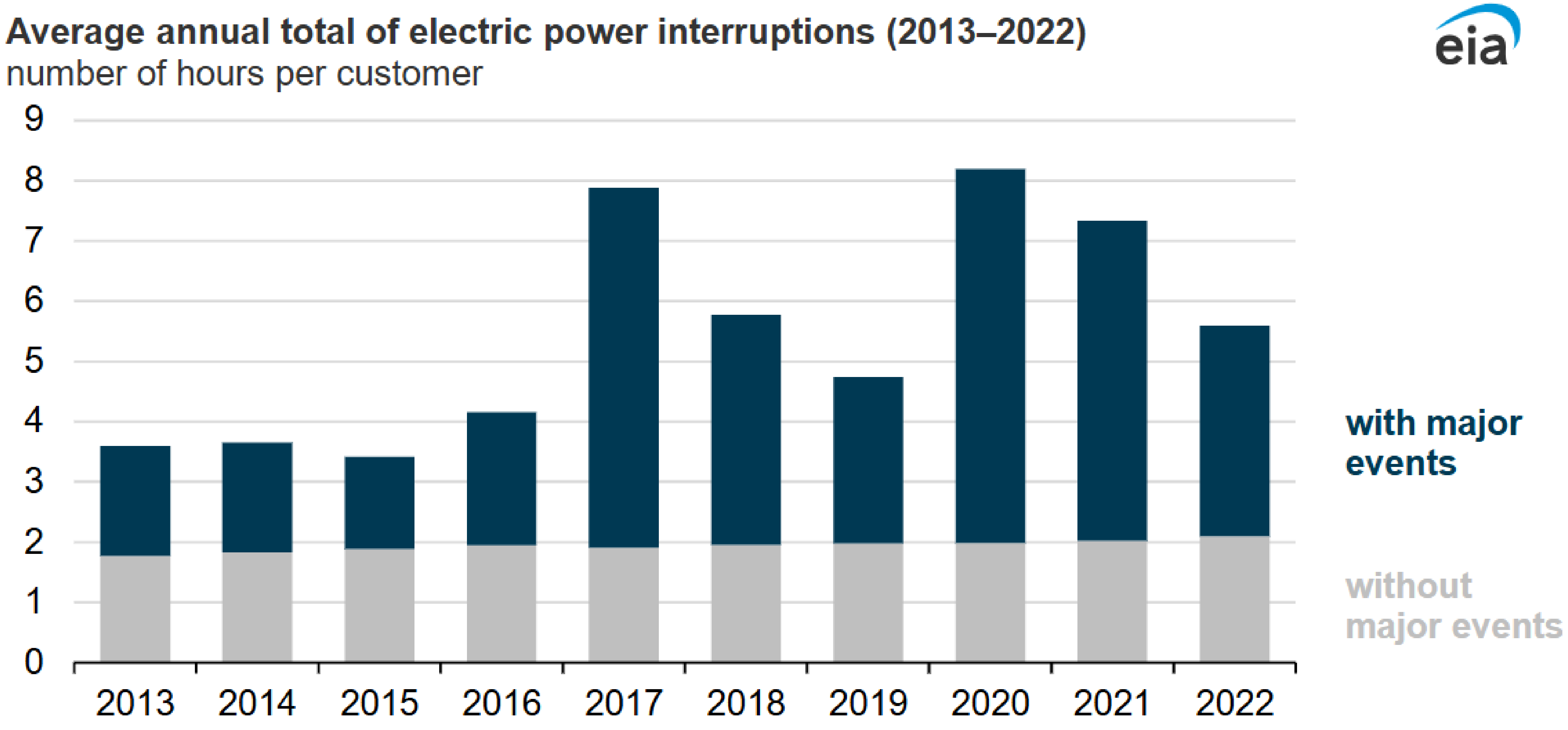
Standard Indices for Small Events (IEEE Std 1366-2022)

- System Average Interruption Duration Index (SAIDI) represents the average amount of time the supply to a customer is interrupted per year (expressed in minutes per year)
- System Average Interruption Frequency Index (SAIFI) represents the average number of times per year the supply to a customer is interrupted per year (expressed in interruptions per year)
  - Both are averages for a system, so some people have higher values, some lower

IEEE Std 1366-2022 Major Event Days (MED)

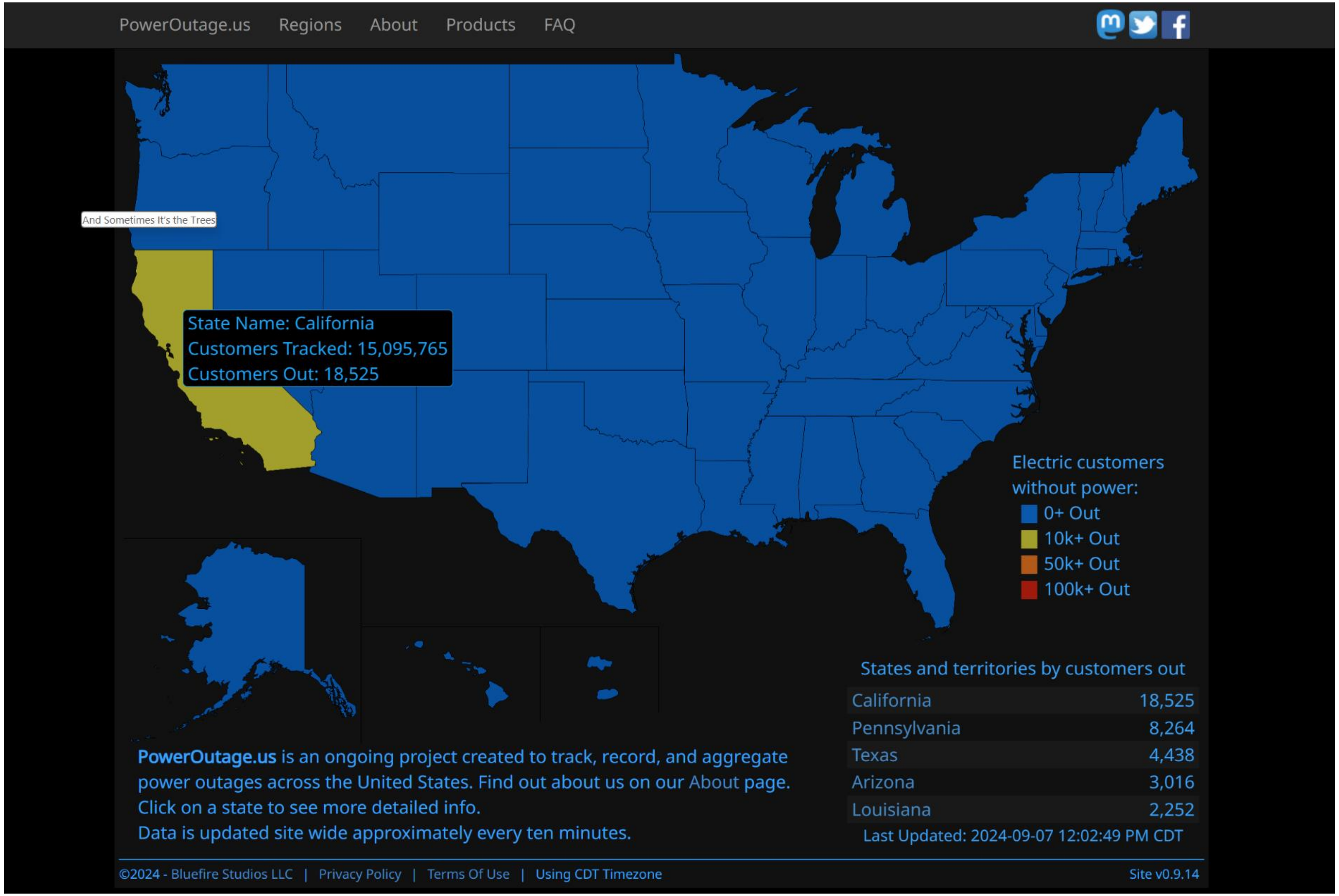
- A MED is a day in which the SAIDI exceeds a threshold; all indices are calculated with the MEDs removed
  - Typically one per year (give or take)
  - Purpose of removal is to allow indices to give good indication of normal operational and design stress
  - MEDs are analyzed separately
  - Just looking at standard indices doesn't indicate what is really going on.

US Blackout Averages



Data source: U.S. Energy Information Administration, *Annual Electric Power Industry Report*

A Good Source for Real-Time US Power Outage Information: https://poweroutage.us



Cost of Blackouts

- Electricity has varying value and hence the costs associated with blackouts can vary substantially
  - Momentary (less than five minutes) can have almost no impact for residential customers (certainly with exceptions!) while costing industrials potentially millions if production is interrupted
- Costs impact are sensitive to the duration and extent of the blackout as well
  - Long duration blackouts impacting a wide area are the worst case scenarios

Larger Scale Blackouts

- The North American Electric Reliability Corporation (NERC) requires reporting of events the interrupt more than 300 MWs or affect at least 50,000 customers
  - From 1984 to 2006 there were 861 events reported, but only about 300 met the criteria
  - Average of blackouts that met the criteria affected several hundred thousand customers, but large outages affected many more (like August 14, 2003 with more than 50 million people).

This data is now kind of dated, partially because of changes in the availability of information to researchers

Source: www.uvm.edu/~phines/publications/2008/Hines_2008_blackouts.pdf

Large Blackouts in North America By Event Size

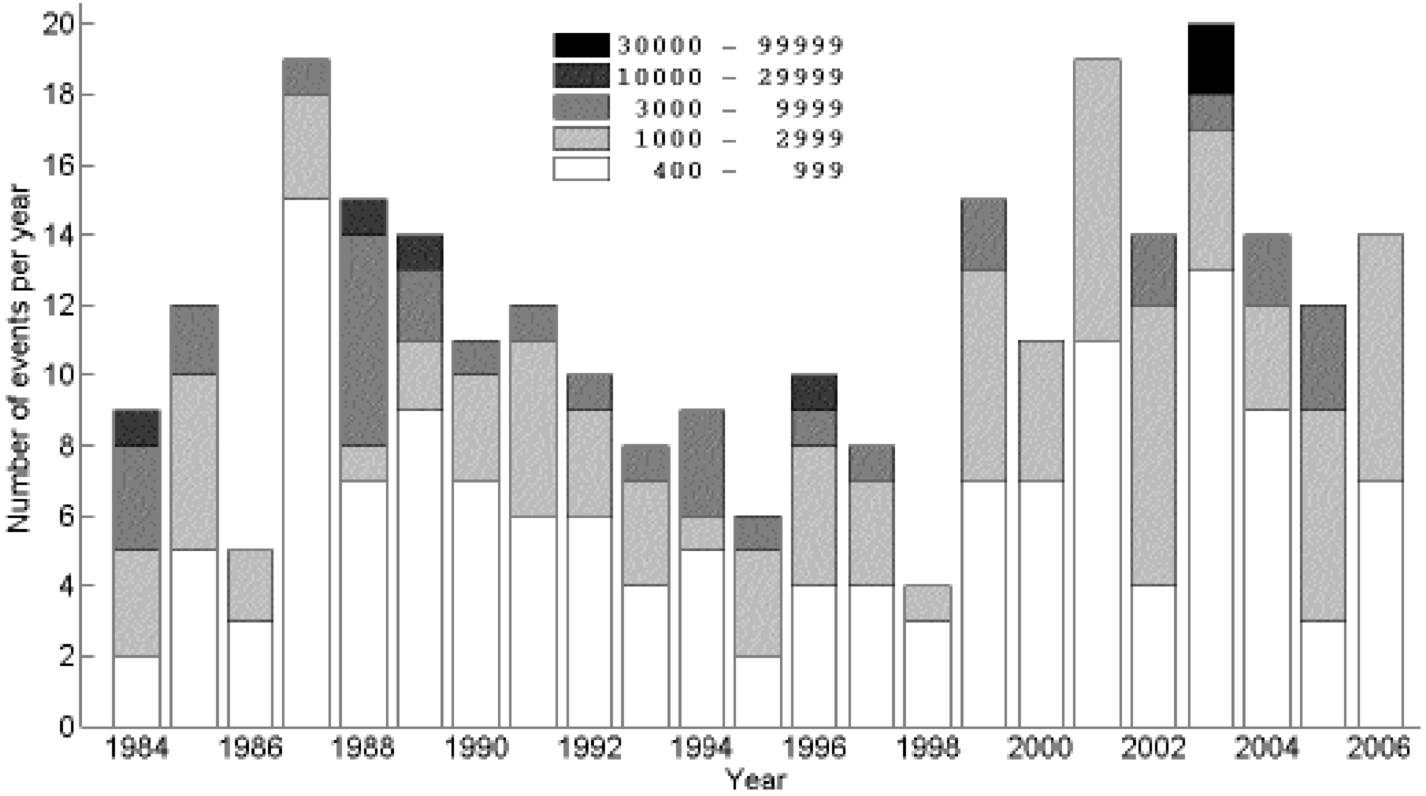


Figure 3. The number of large blackouts per year after removing small events, and controlling for increasing demand. Event size above is shown in year-2000 MW.

Source: www.uvm.edu/~phines/publications/2008/Hines_2008_blackouts.pdf

Causes of Large Blackouts

TABLE 2. STATISTICS FOR DATA CAUSE CATEGORIES

	% of events	Mean size in MW	Mean size in customers
Earthquake	0.8	1,408	375,900
Tornado	2.8	367	115,439
Hurricane/tropical storm	4.2	1,309	782,695
Ice storm	5.0	1,152	343,448
Lightning	11.3	270	70,944
Wind/rain	14.8	793	185,199
Other cold weather	5.5	542	150,255
Fire	5.2	431	111,244
Intentional attack	1.6	340	24,572
Supply shortage	5.3	341	138,957
Other external cause	4.8	710	246,071
Equipment failure	29.7	379	57,140
Operator error	10.1	489	105,322
Voltage reduction	7.7	153	212,900
Volunteer reduction	5.9	190	134,543

Source: www.uvm.edu/~phines/publications/2008/Hines_2008_blackouts.pdf

Avoidable Transmission Level Blackouts

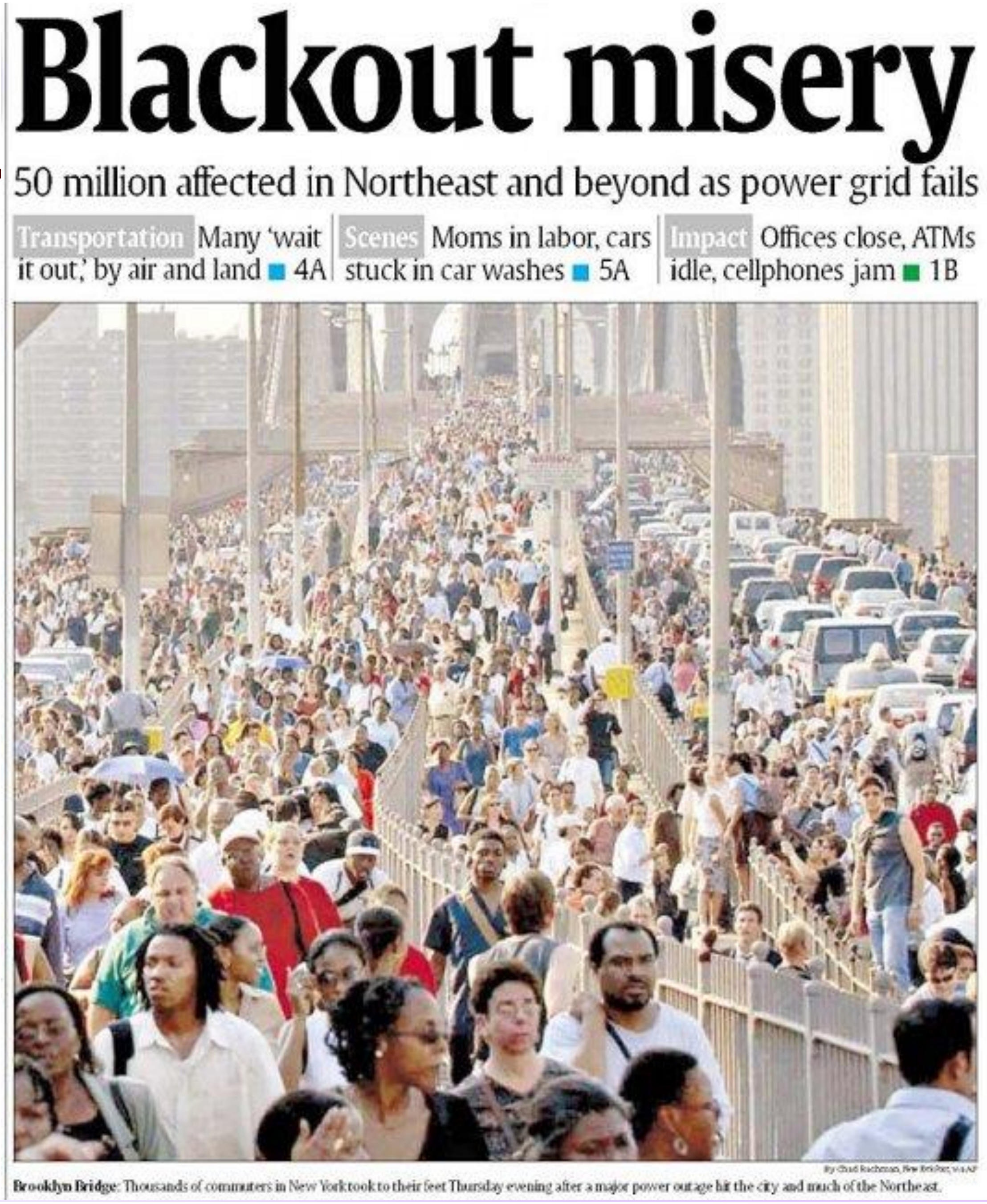
- Many major blackouts can be prevented.
- Time frames of the blackouts, minutes to hours, allow for operator intervention
  - Tokyo 1987 (20 minutes), WECC 1996 (six minutes), Eastern Interconnect 2003 (about an hour), Italy 2003 (25 minutes), India 2012
- And of course many are prevented, and hence do not make the news. For example, near voltage collapse in Delmarva Peninsula, 1999.

Restoration

- The cost of blackouts certainly increases the longer the power is out
- How quickly power can be restored depends on whether there was equipment damage
  - Downed lines take time to rebuild
  - Houses damaged by flooding need to be disconnected before service can be restored
  - Some generation, such as nuclear plants, can take days to restart
  - Damage to HEV transformers could be catastrophic!

August 14th 2003 Blackout and Winter Storm Uri 2001

- The August 14th 2003 blackout is now more than 20 years in the past 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"
- We'll also briefly cover Winter Storm Uri, which resulted in rotating blackouts in Texas



Blackout misery

50 million affected in Northeast and beyond as power grid fails

Transportation Many 'wait it out,' by air and land ■ 4A

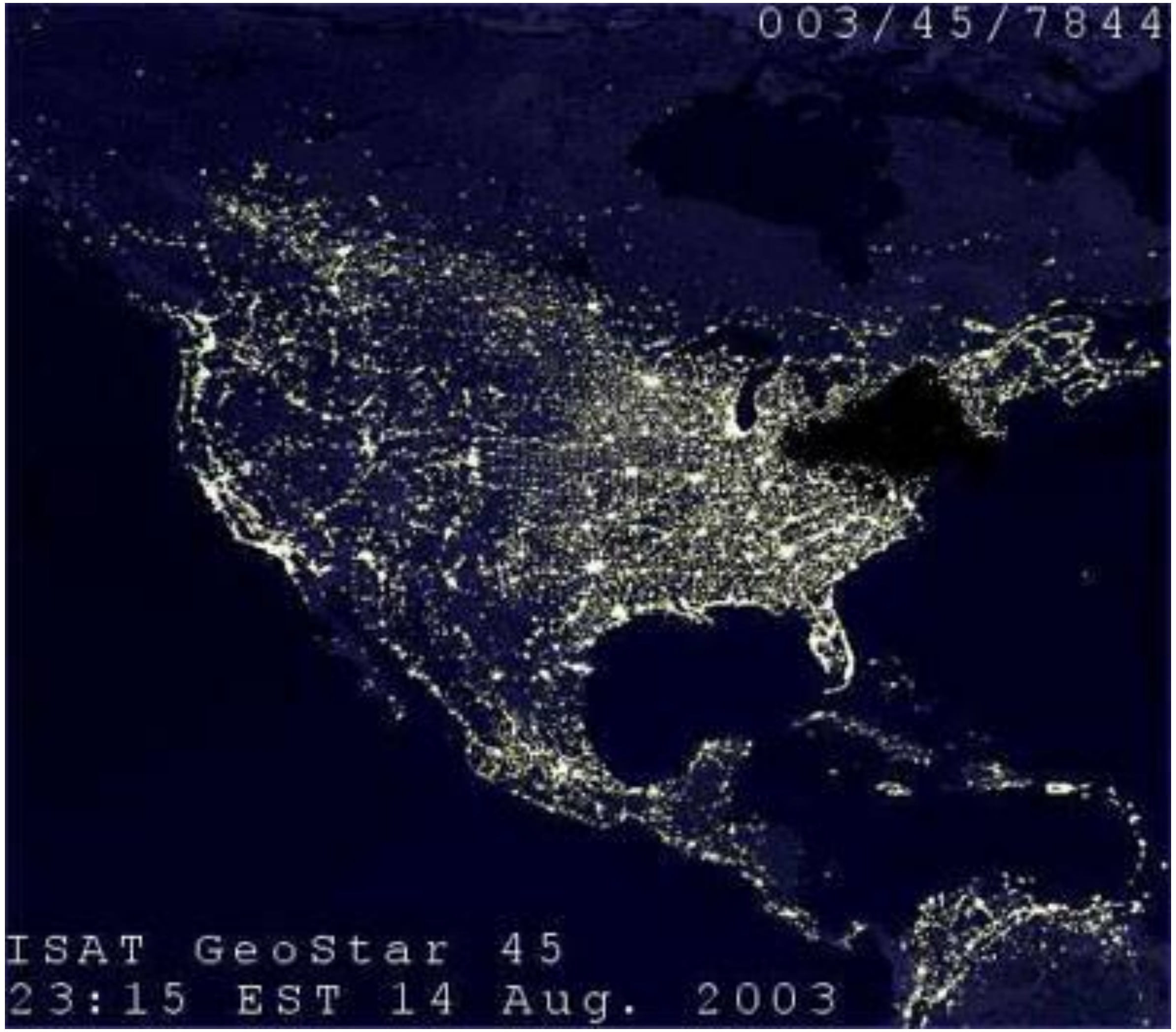
Scenes Moms in labor, cars stuck in car washes ■ 5A

Impact Offices close, ATMs idle, cellphones jam ■ 1B

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.

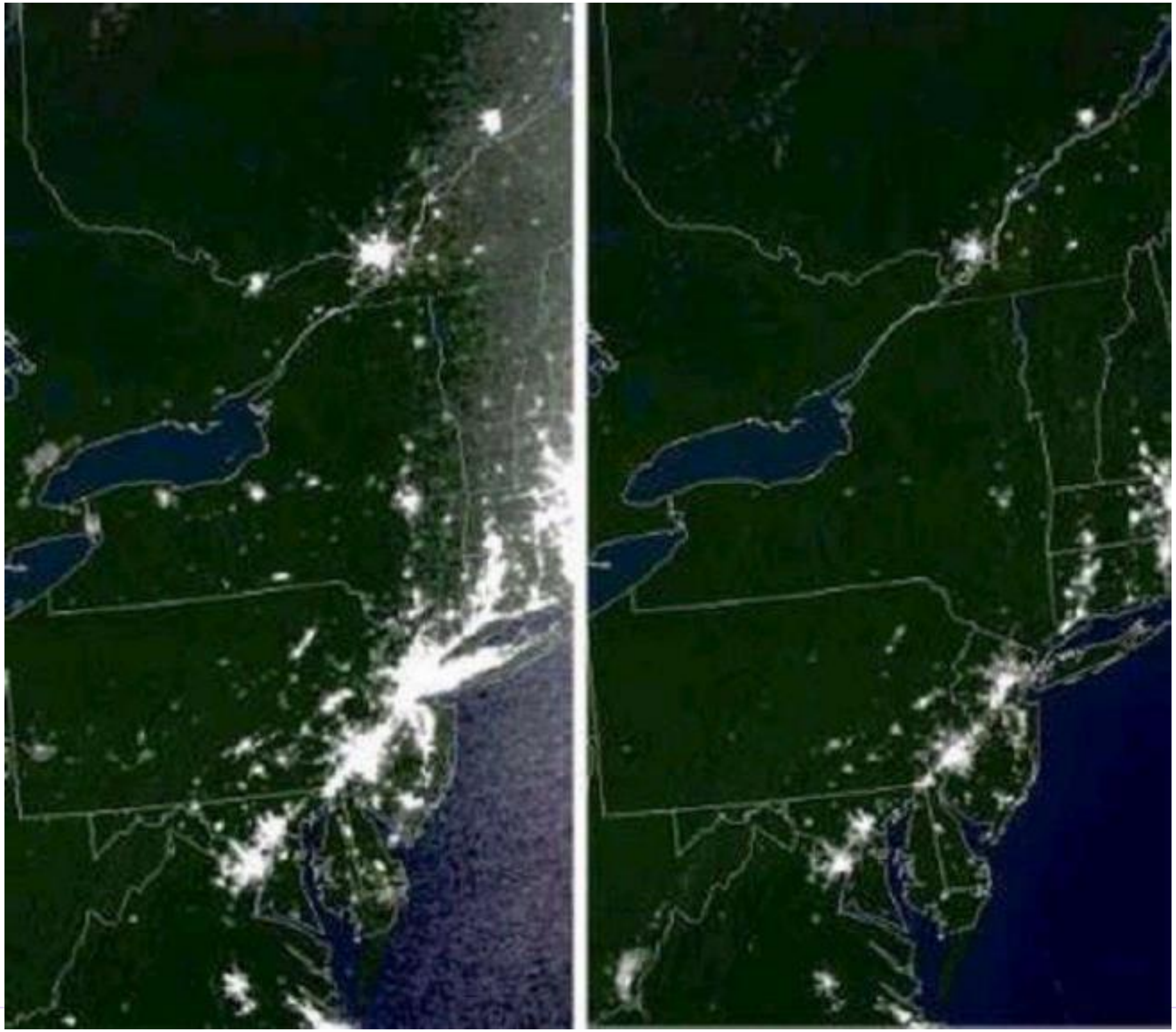
The August 14 2003 Blackout affected about 50 million people in the US and Canada. There have been much larger blackouts, including one in 2012 that affected more than 620 million people in India, and one in 2023 in Pakistan affecting more than 200 million. The 8/14/2003 one is still the largest in North America; the New York 1965 one affected 30 million, while Winter Storm Uri affected more than 15 million people in Texas in 2021 with at least rotating outages.

August 14, 2003 Hoax Image



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



My Favorite August 14, 2003 Cartoon

Suddenly, knowing a lot about the U.S. power grid became sexy at cocktail parties.

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 2025
- Need to keep in mind economic impact of 8/14/03 was above $5 billion; yearly impact of blackouts could be above $100 billion

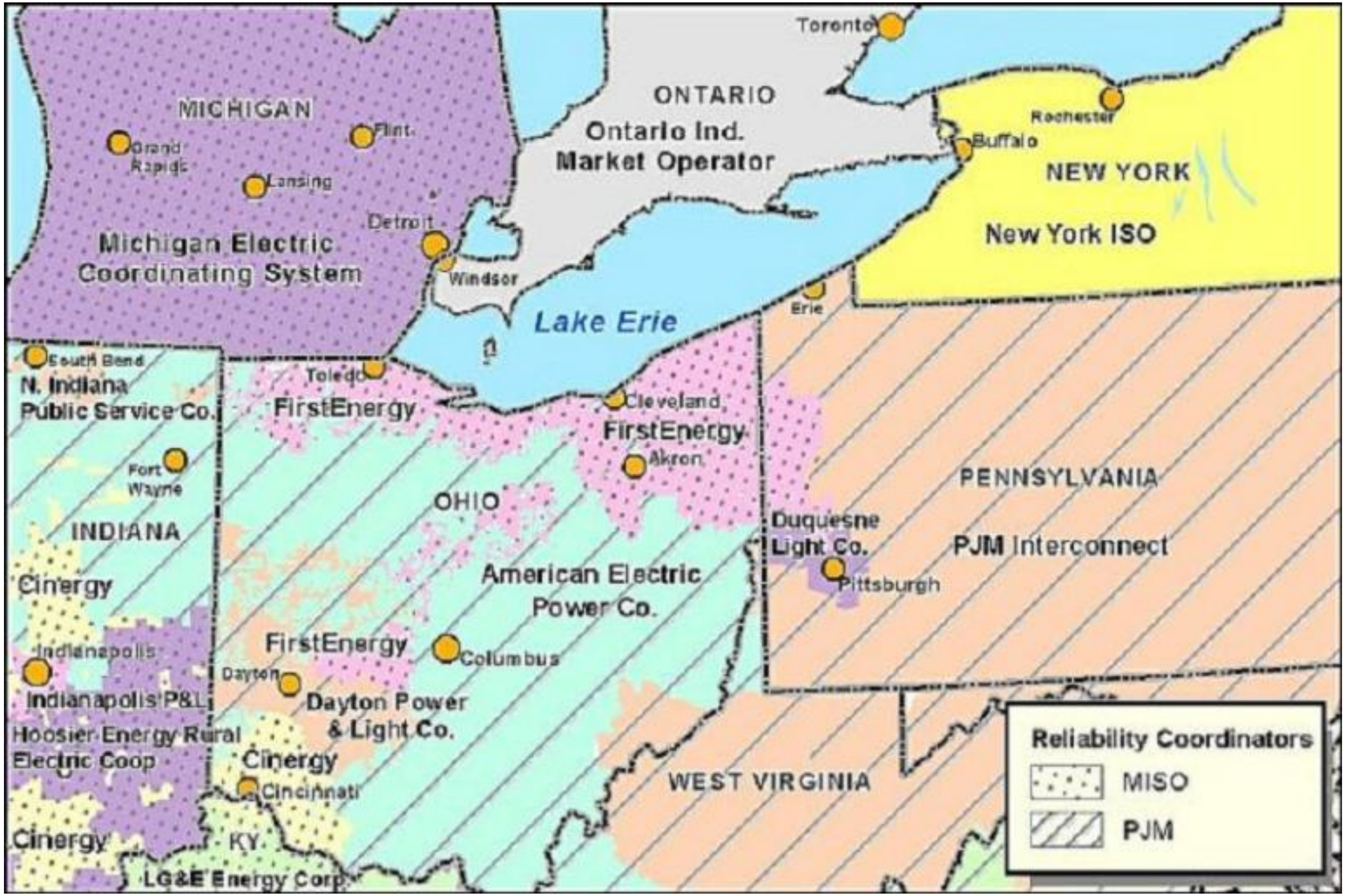
First Energy Control Center, (2013)

Image Source:
www.wksu.org/news/story/365

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

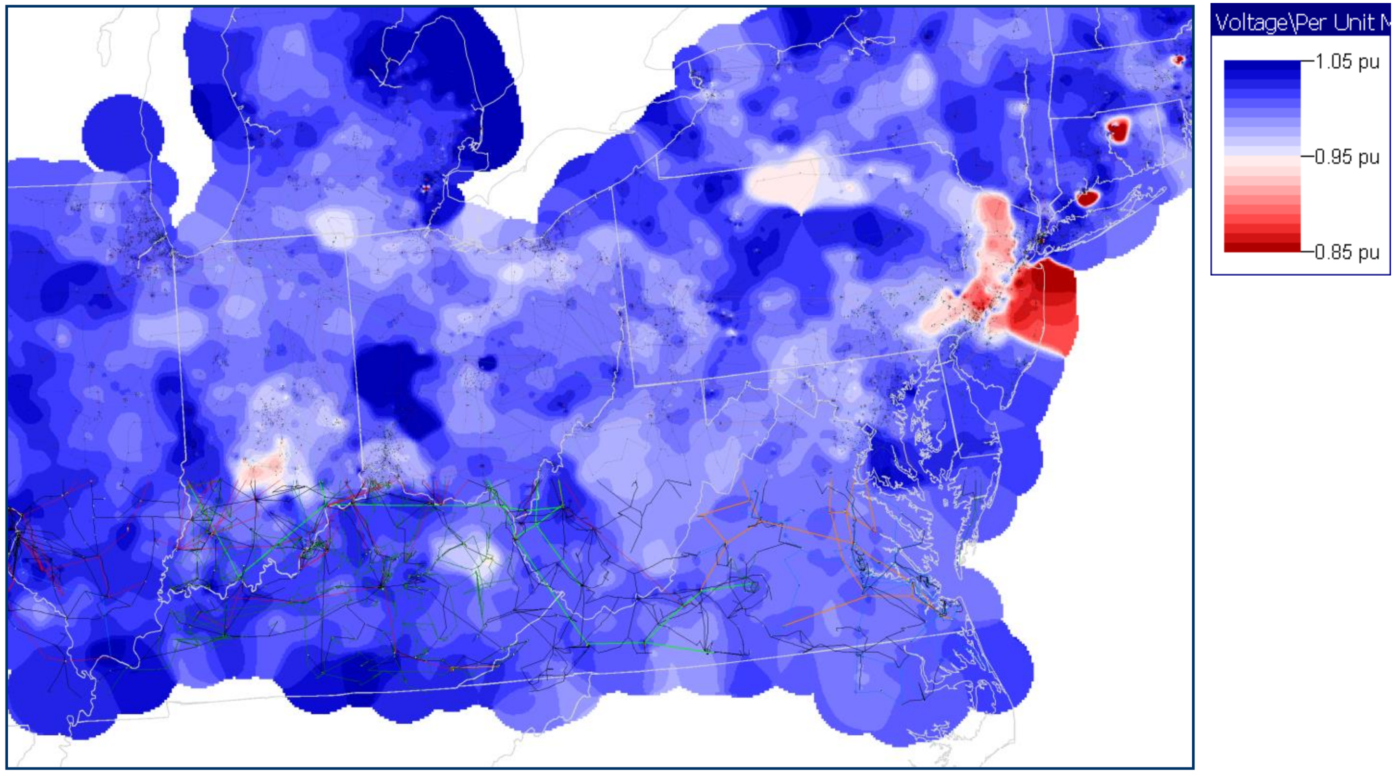
Footprints of Reliability Coordinators in Midwest



In 2003 the Ohio portion of First Energy was in MISO; they have since moved to being in PJM.

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

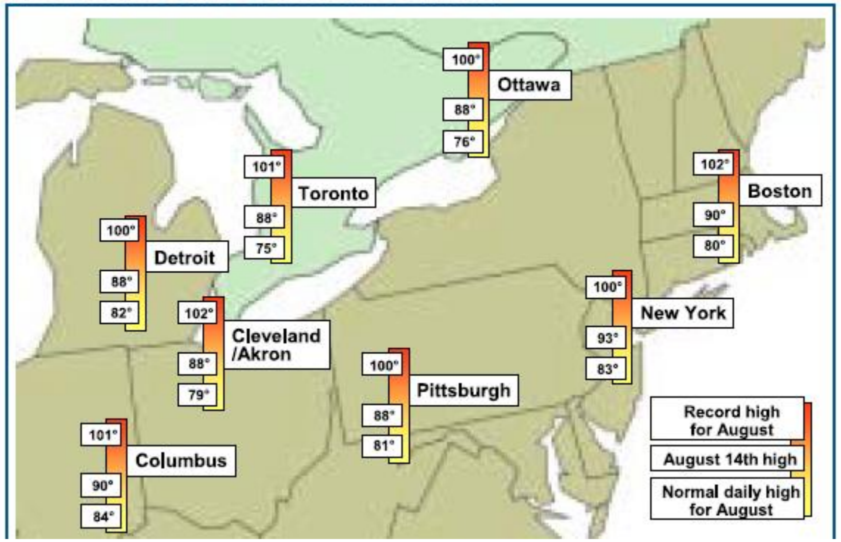


NERC 2003 Summer Assessment is available at http://www.nerc.com/files/summer2003.pdf

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

Figure 4.1. August 2003 Temperatures in the U.S. Northeast and Eastern Canada



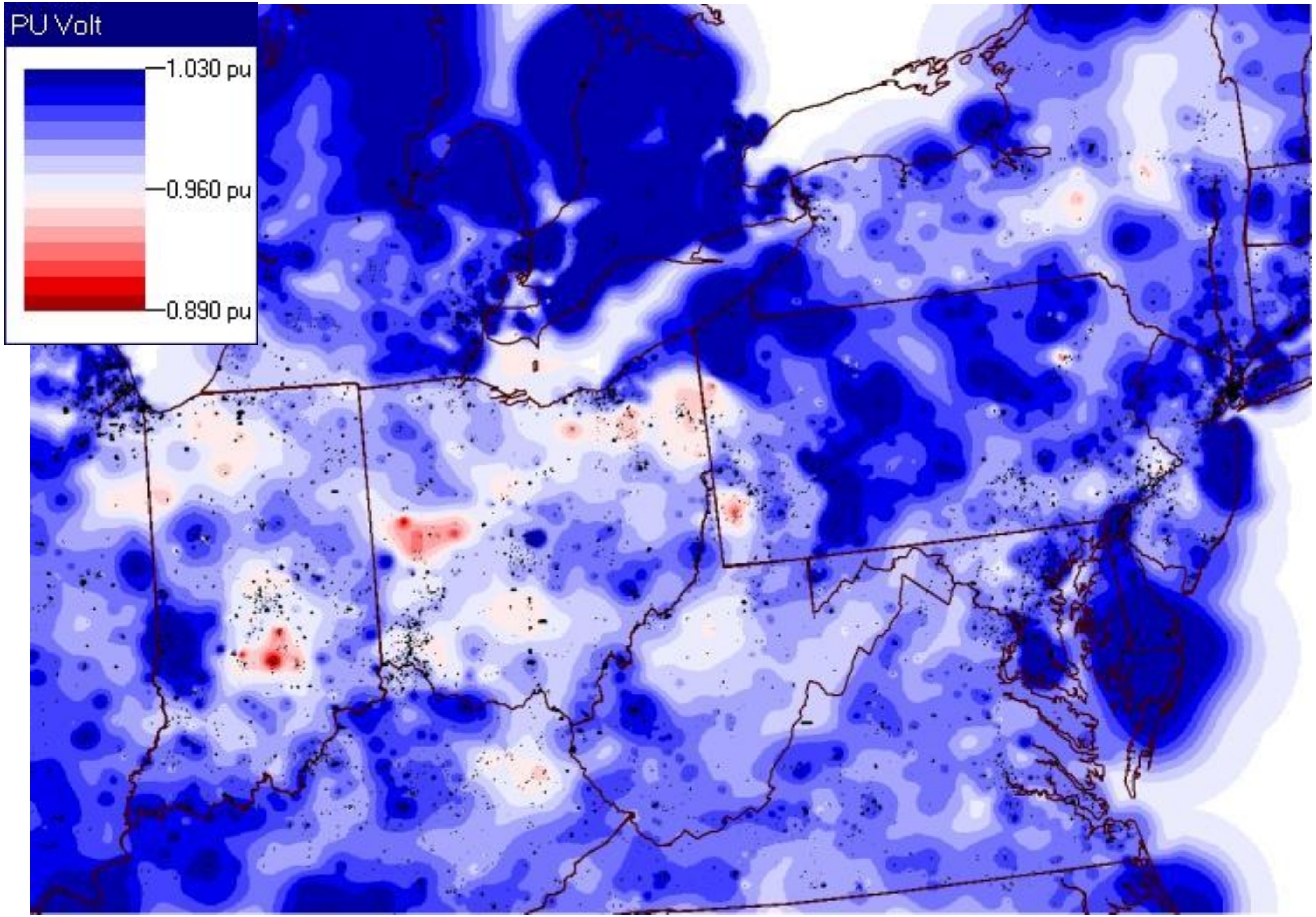
Cinergy Bedford-Columbus 345 kV Line Tree Contact at 12:08 EDT

Trees were Finally “Trimmed” Two Months Later

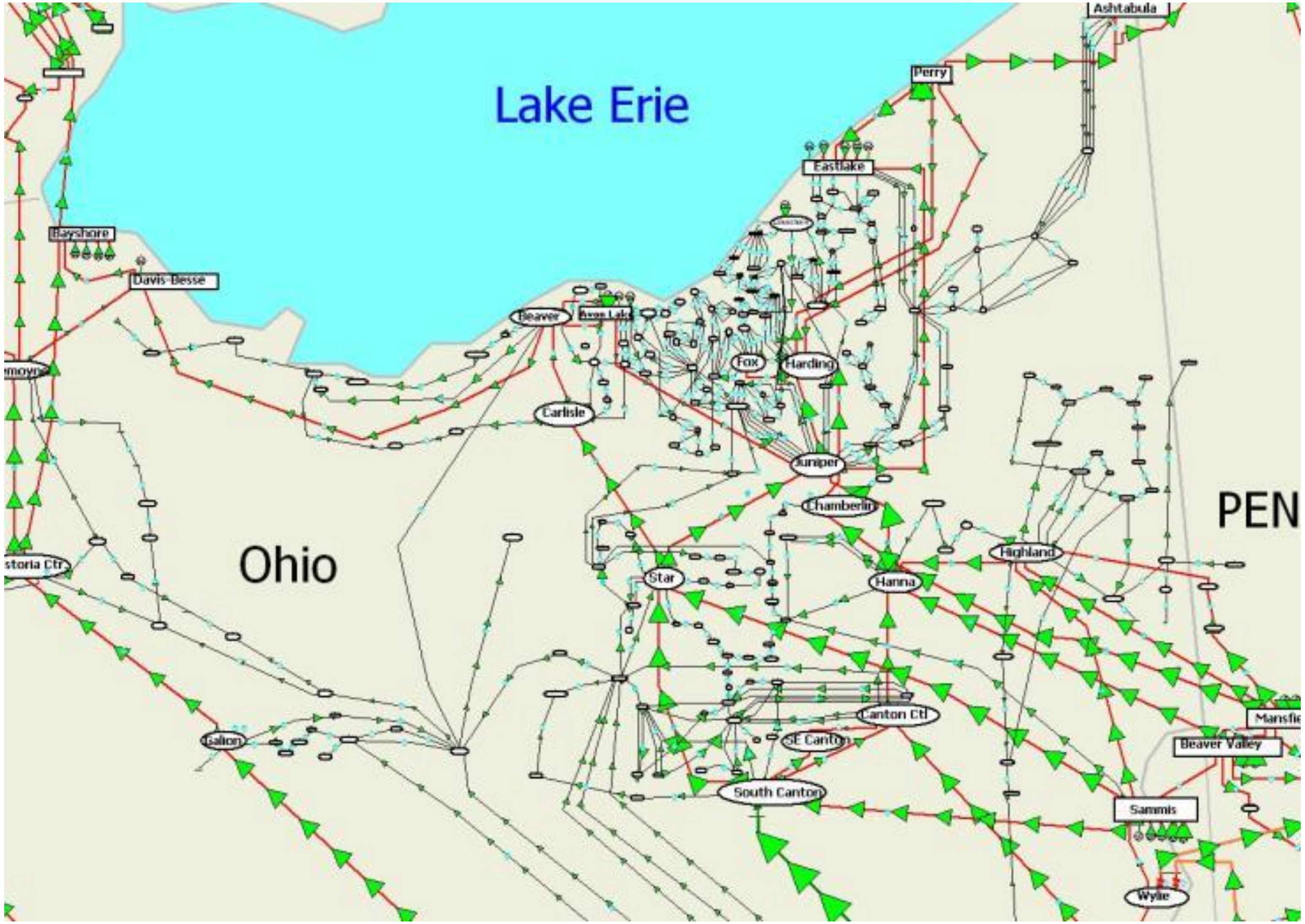
At 14:27 EDT Star-South Canton 345 kV Line Trips and Recloses

- 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

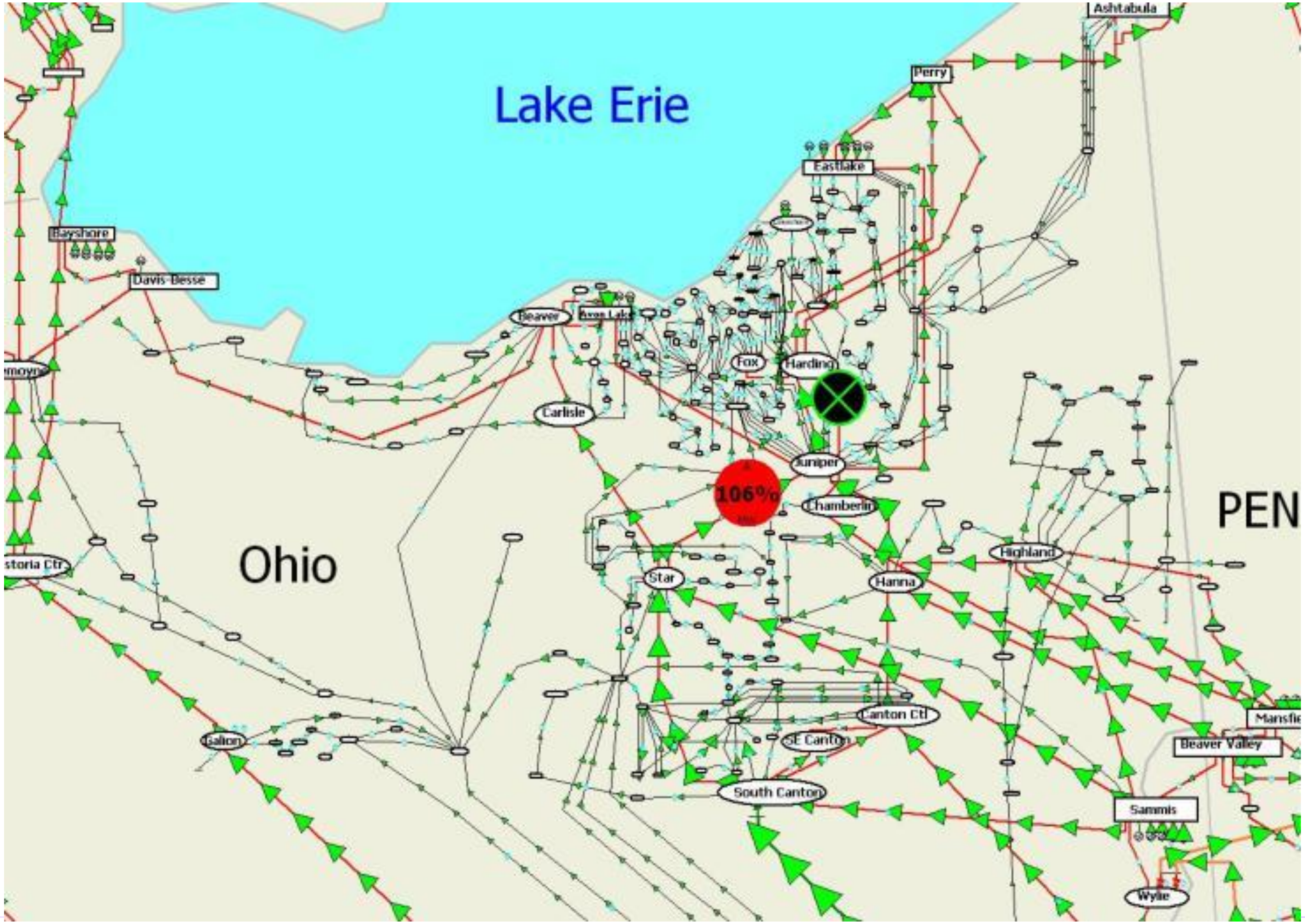


Estimated Flows in Northeast Ohio at 15:00 EDT on August 14th 2003



Chamberlin-Harding 345 kV Line trips at 15:05, an event that was missed by both FE and MISO

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

$$\Delta f_{\ell} = d_{\ell,k} \; f_k^0$$

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 can be used as proxies for other types of limits, such as voltage or stability limits
- Flowgates in 2003 were calculated using a spreadsheet

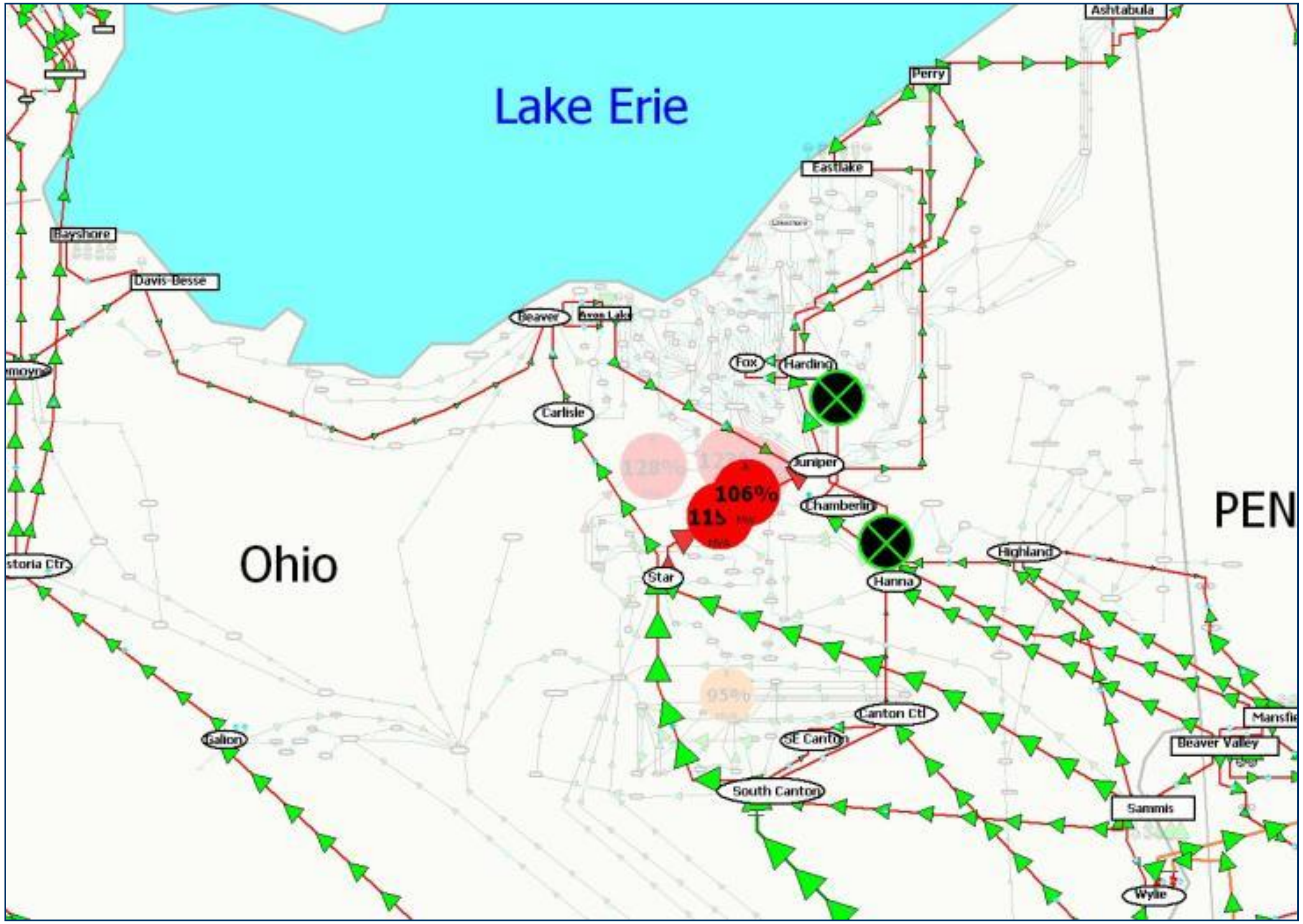
Flowgate #2265

- 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
- Information on PJM’s current flowgates is available at www.pjm.com/markets-and-operations/etools/oasis/atc-information

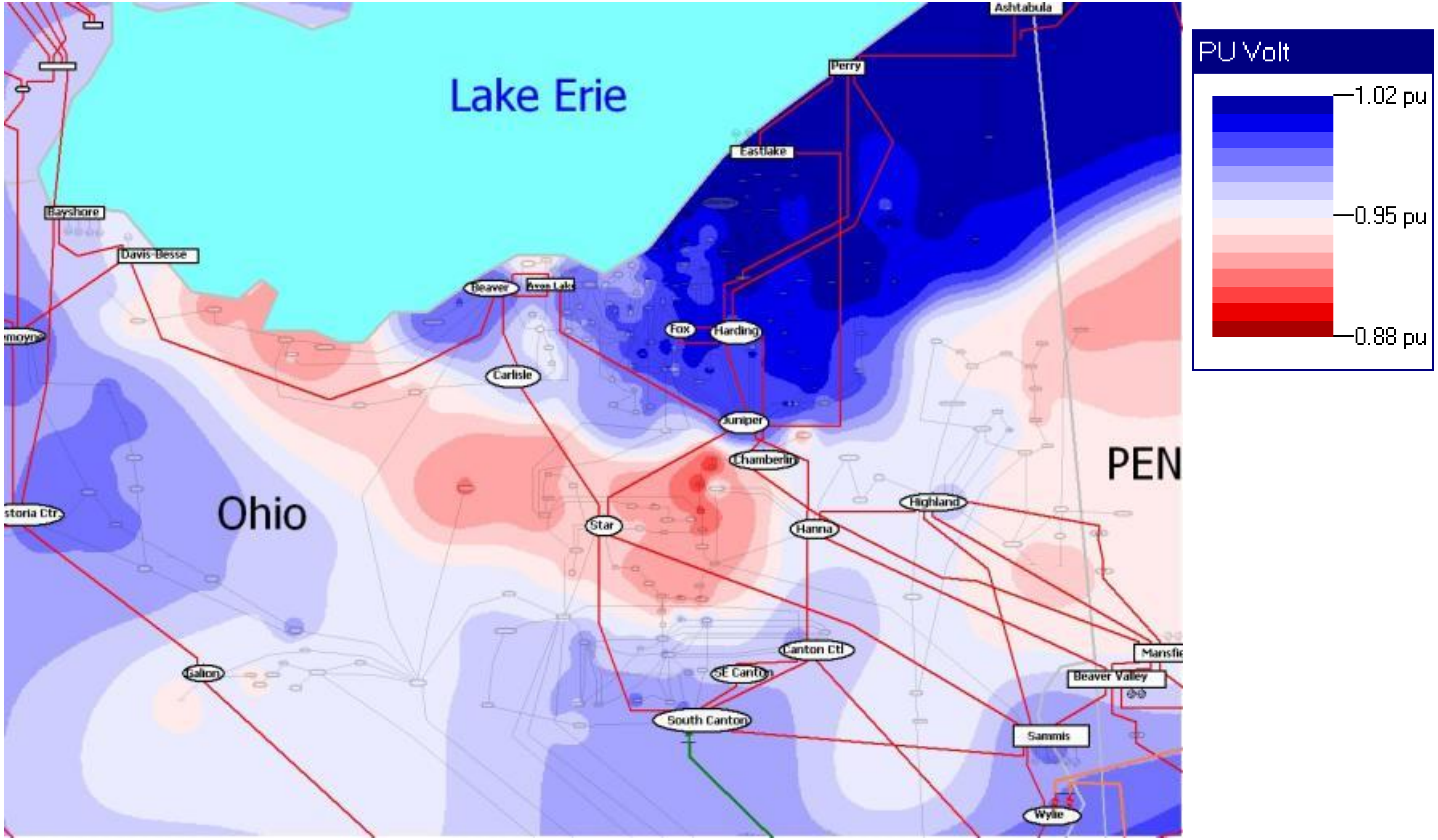
The Bad LODF that Maybe Blacked Out the Northeast

- 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



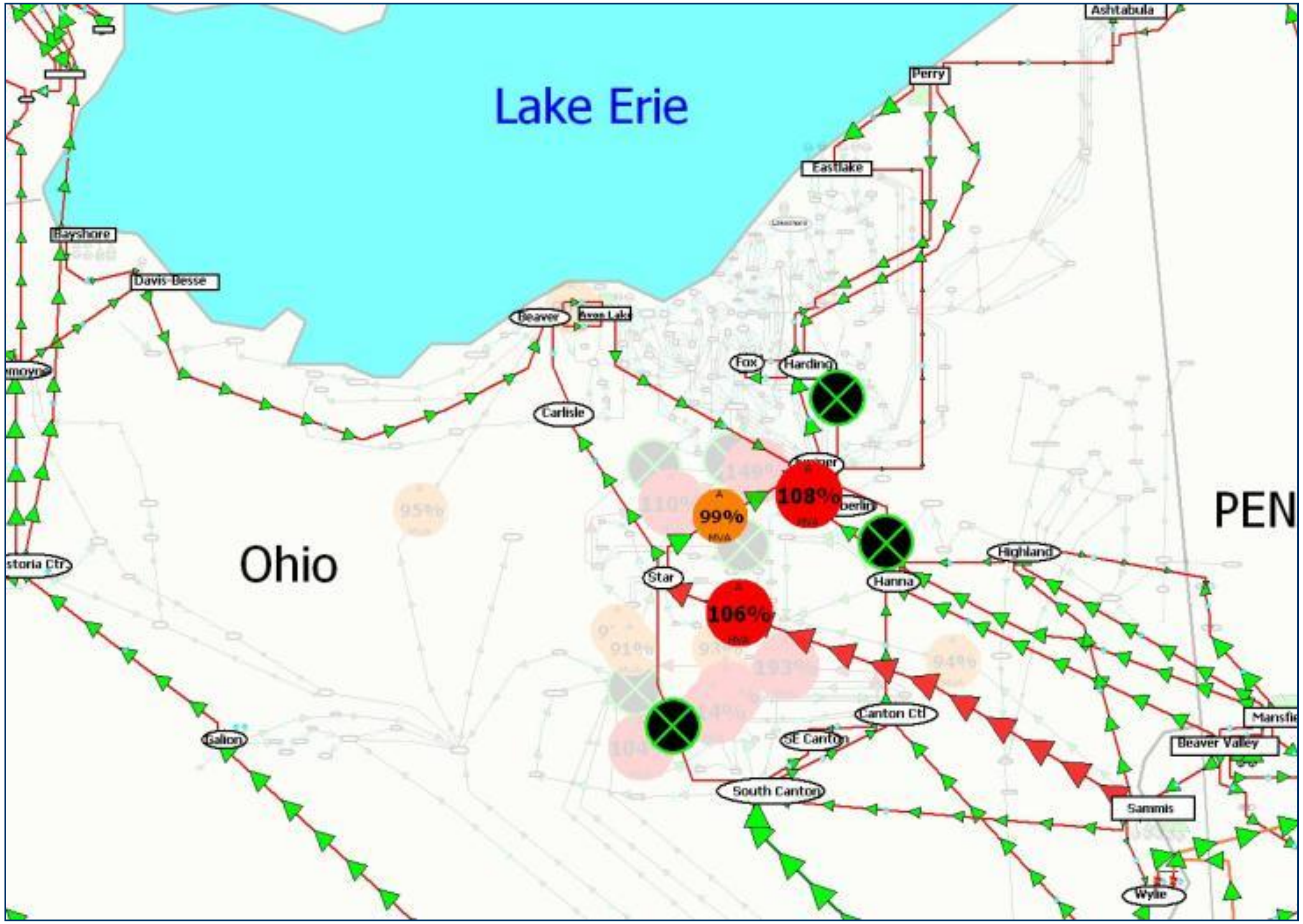
Estimated Northeast Ohio 138 kV Voltage Contour: 15:33 EDT



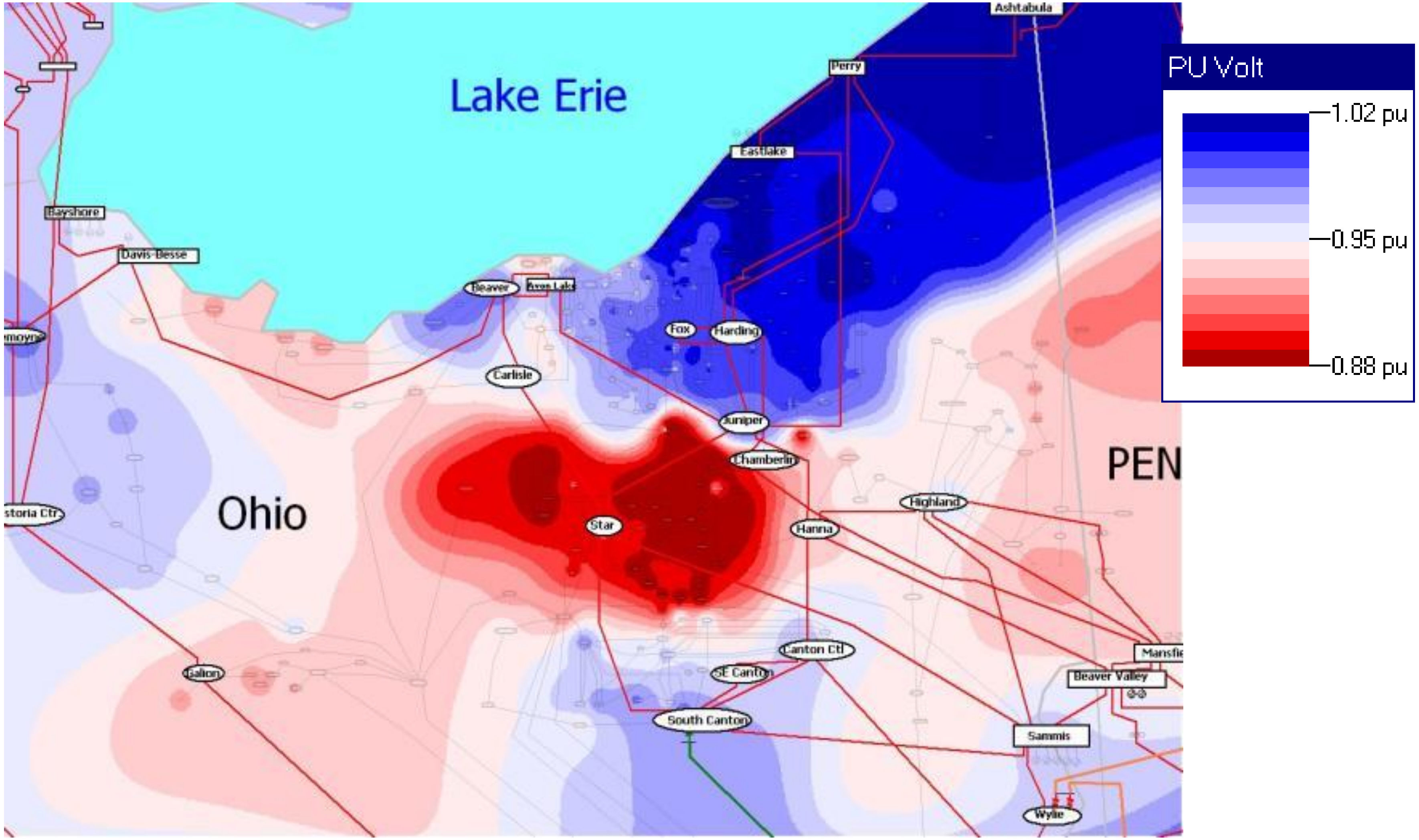
IT Issues

- 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.

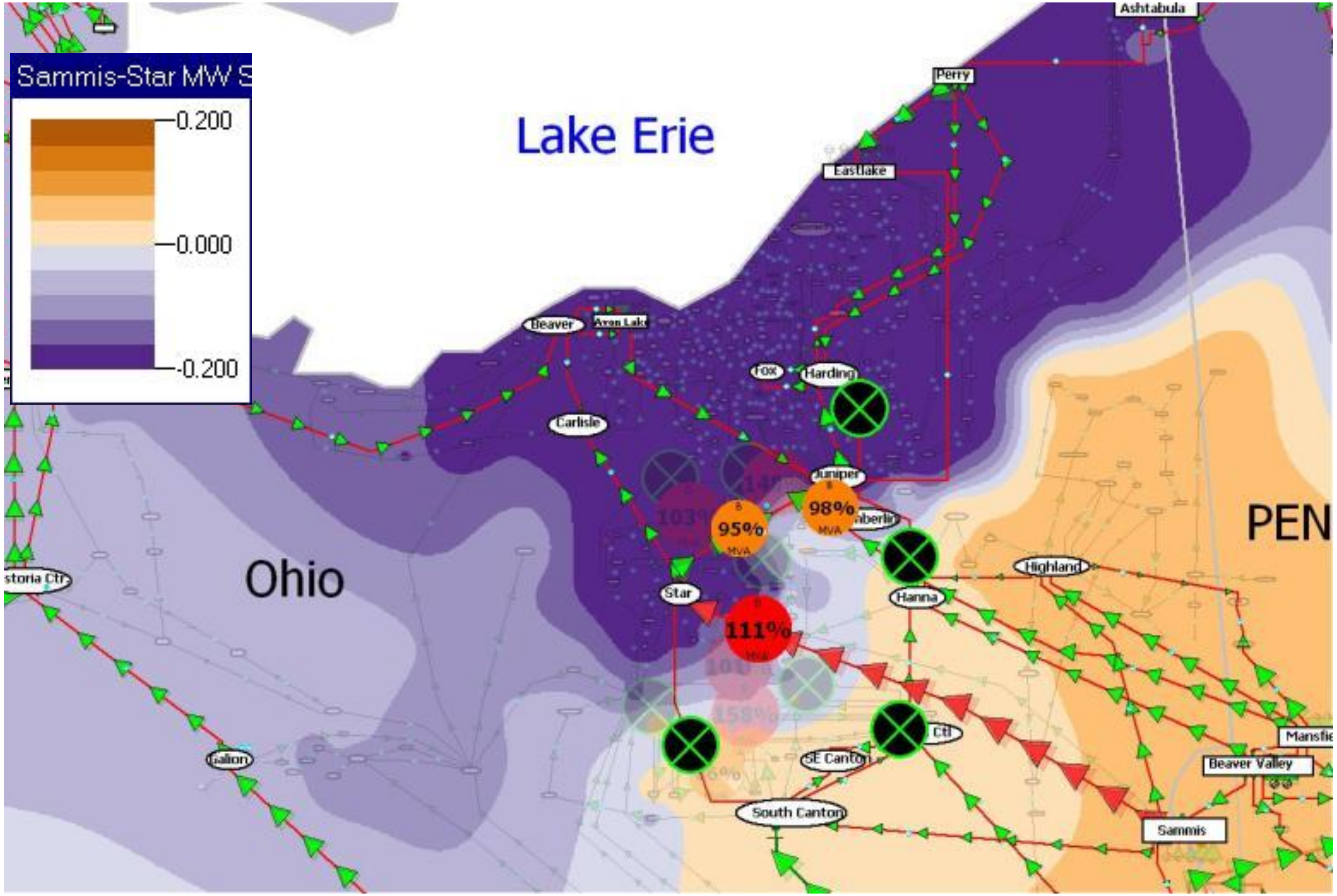
Estimated Flows in Northeast Ohio at 15:46 EDT on August 14th 2003



Estimated Northeast Ohio 138 kV Voltage Contour: 15:46 EDT

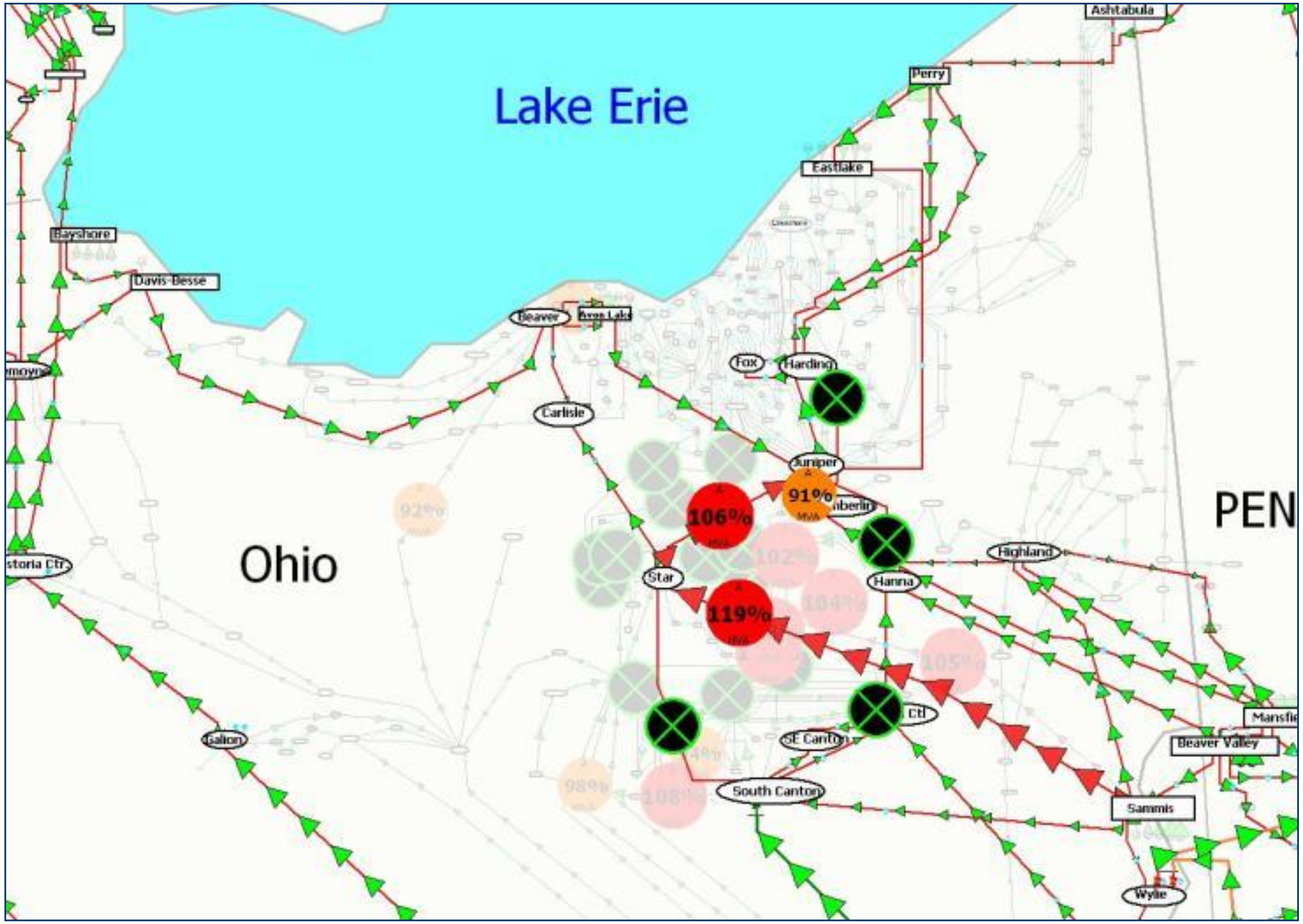


What Could Have Been Done? Sammis-Star Flow Sensitivities

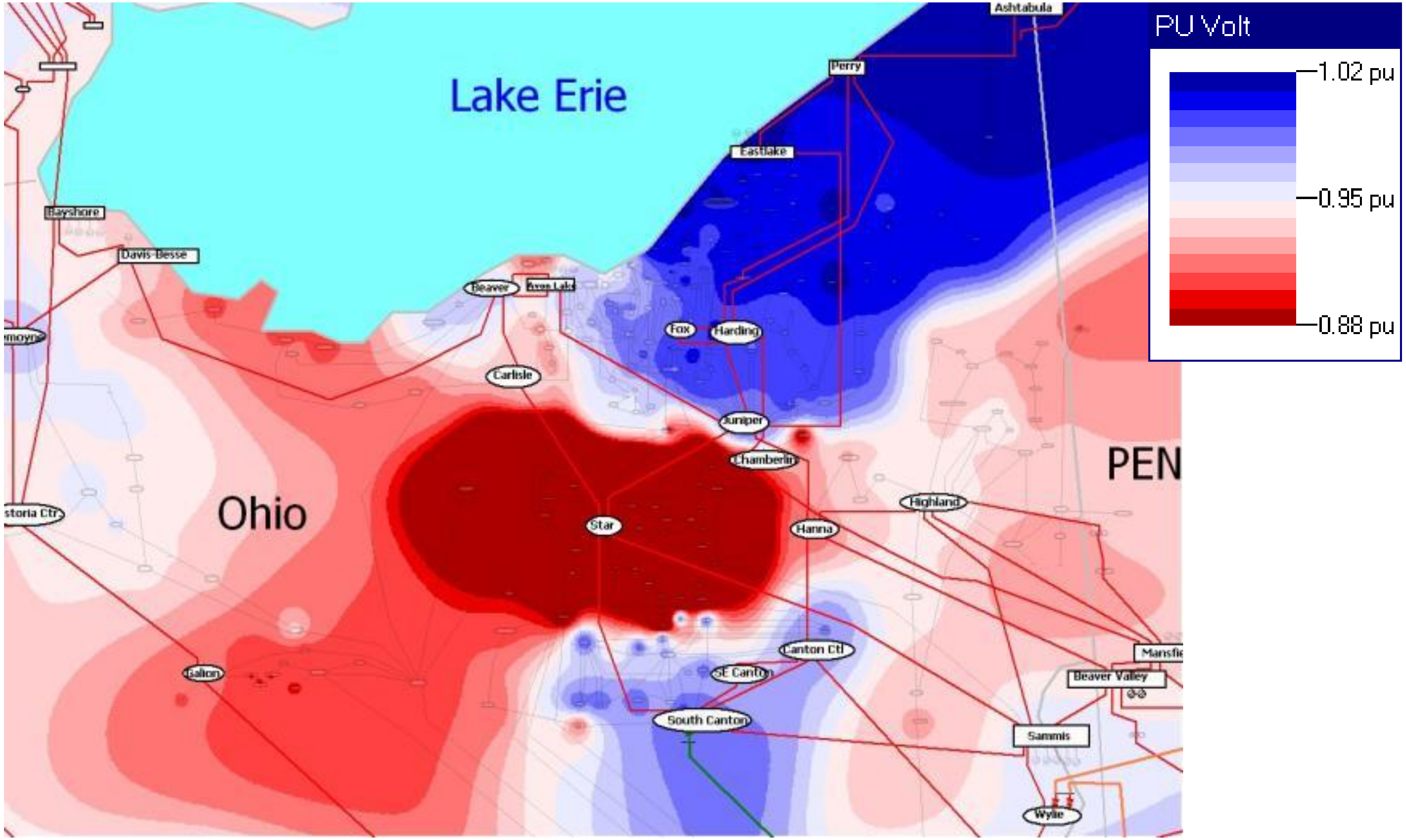


DOE/NERC report said about 1500 MW of load shed would have been needed

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



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



Path to Cleveland Blocked after Loss of Sammis-Star 16:05:57

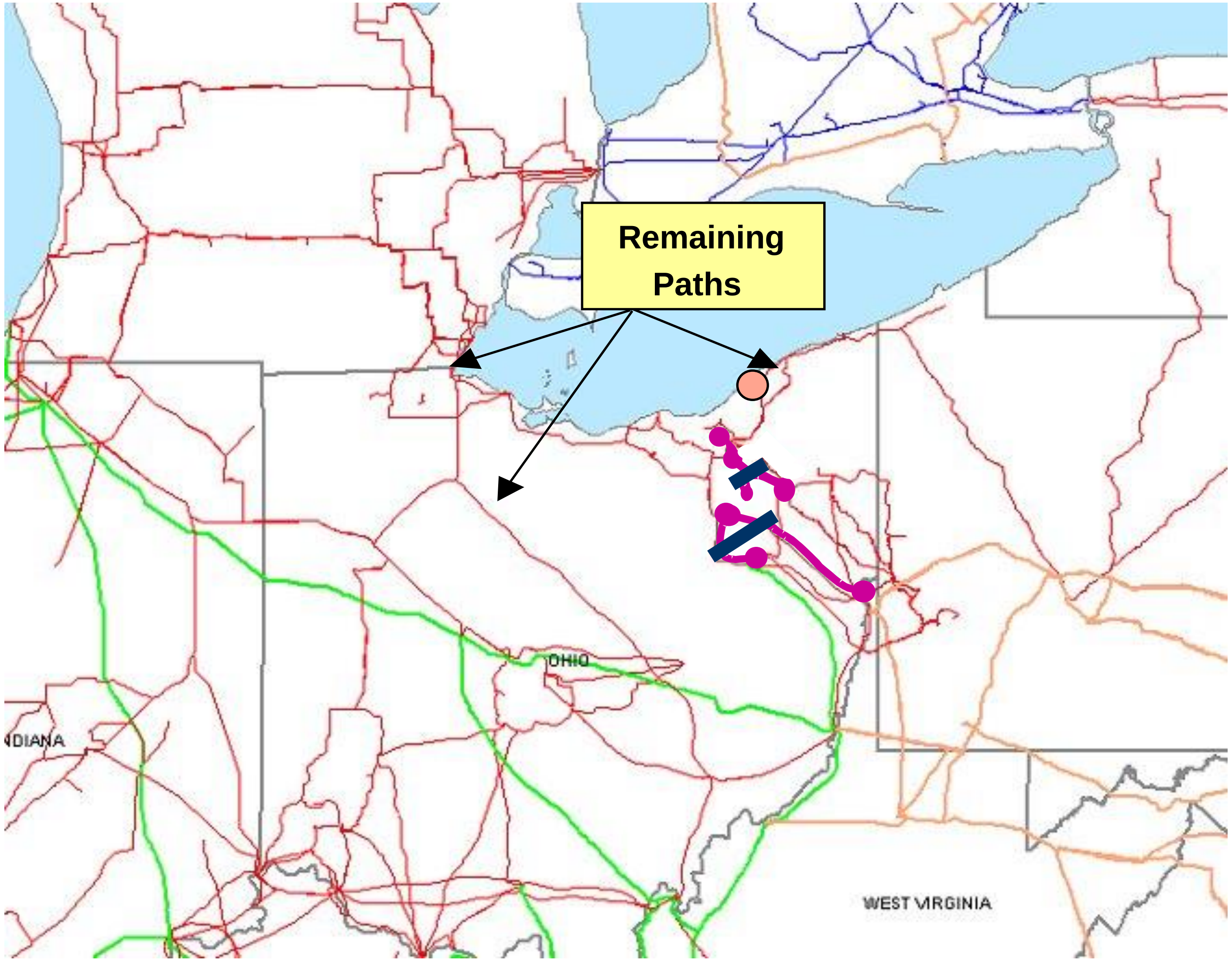
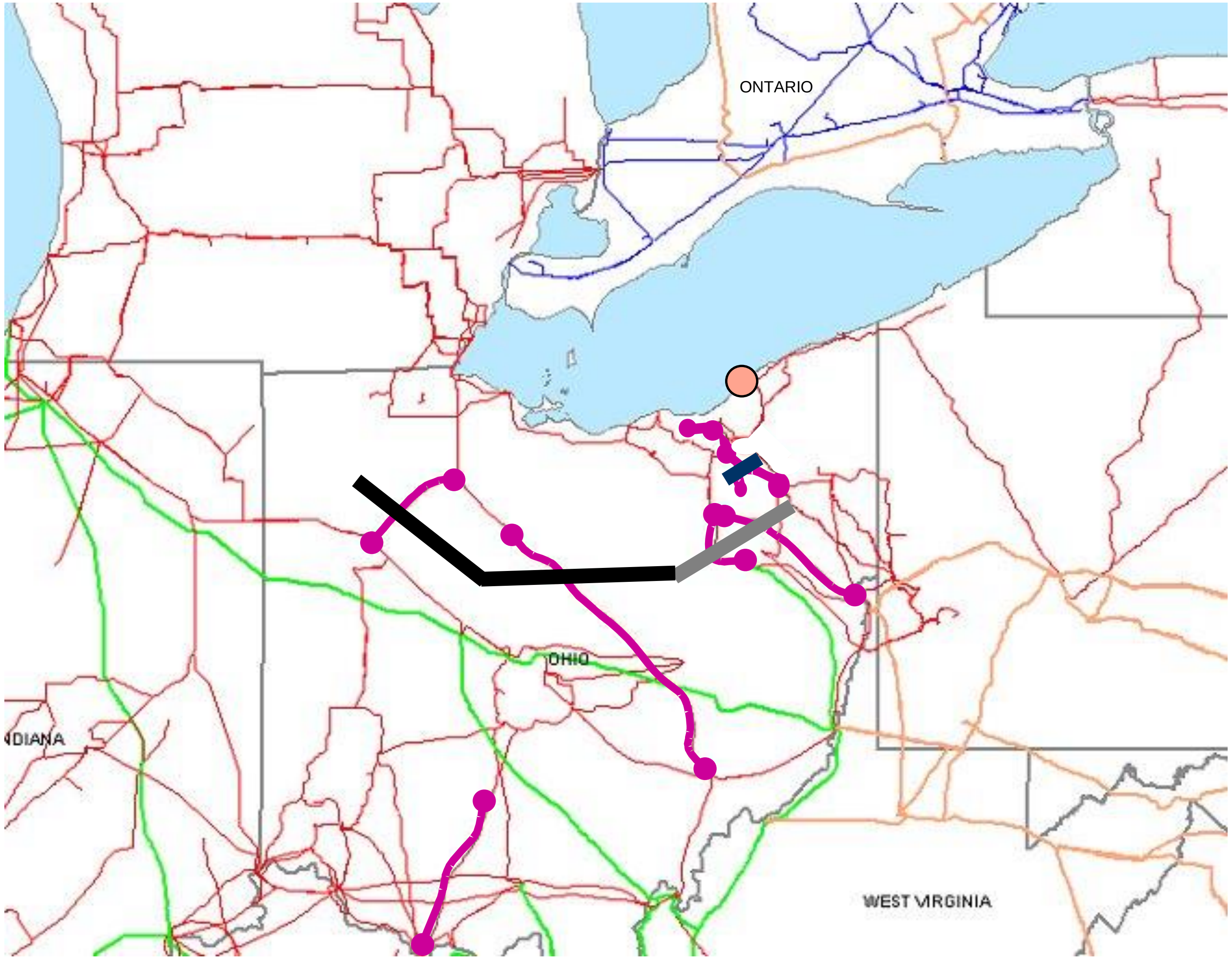


Image Source: August 14 2003 Blackout Final Report

345 kV Lines Trip Across Ohio to West at 16:09



Generation Trips 16:09:08 – 16:10:27

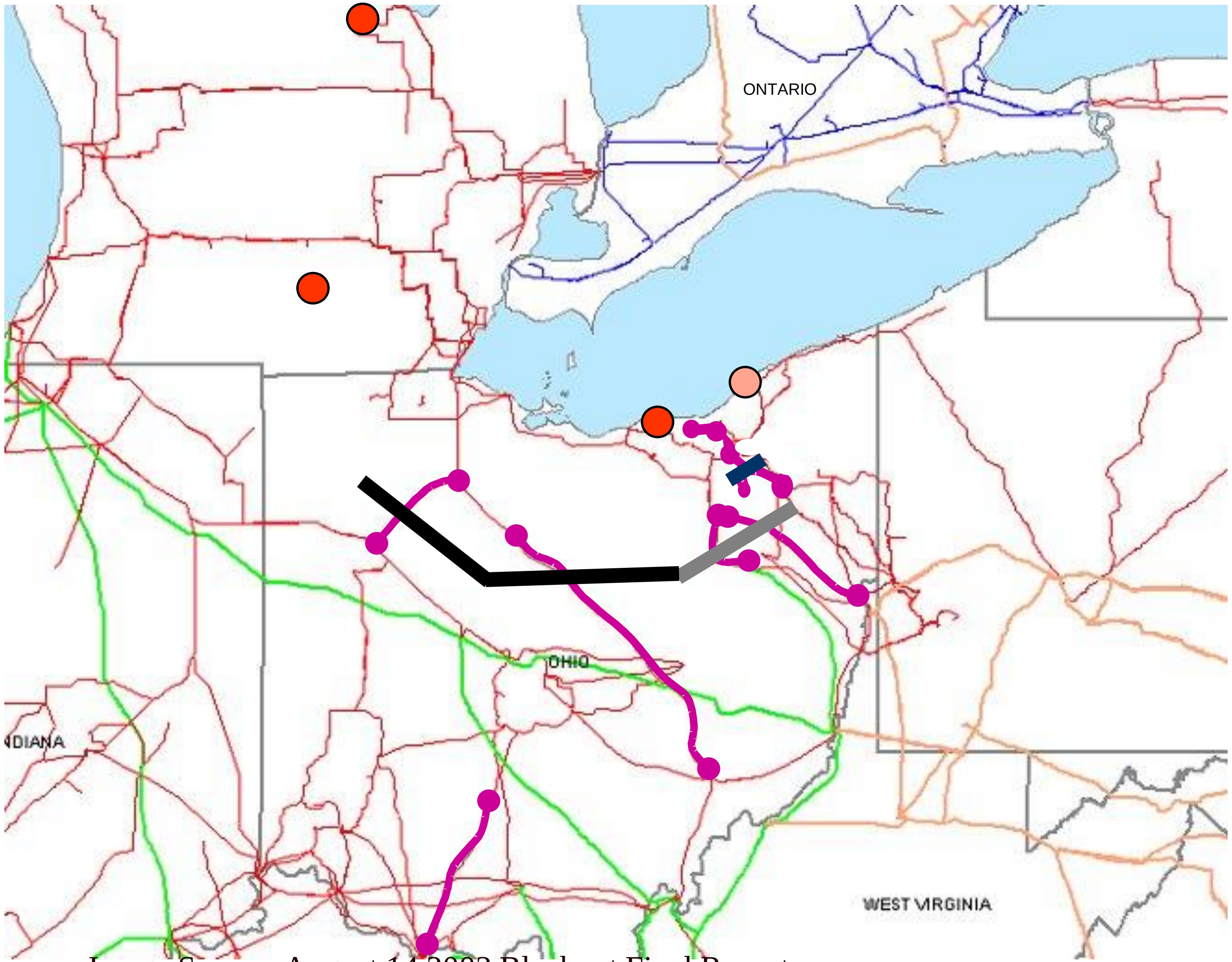


Image Source: August 14 2003 Blackout Final Report

Parts of Ohio/Michigan Served Only from Ontario after 16:10:37

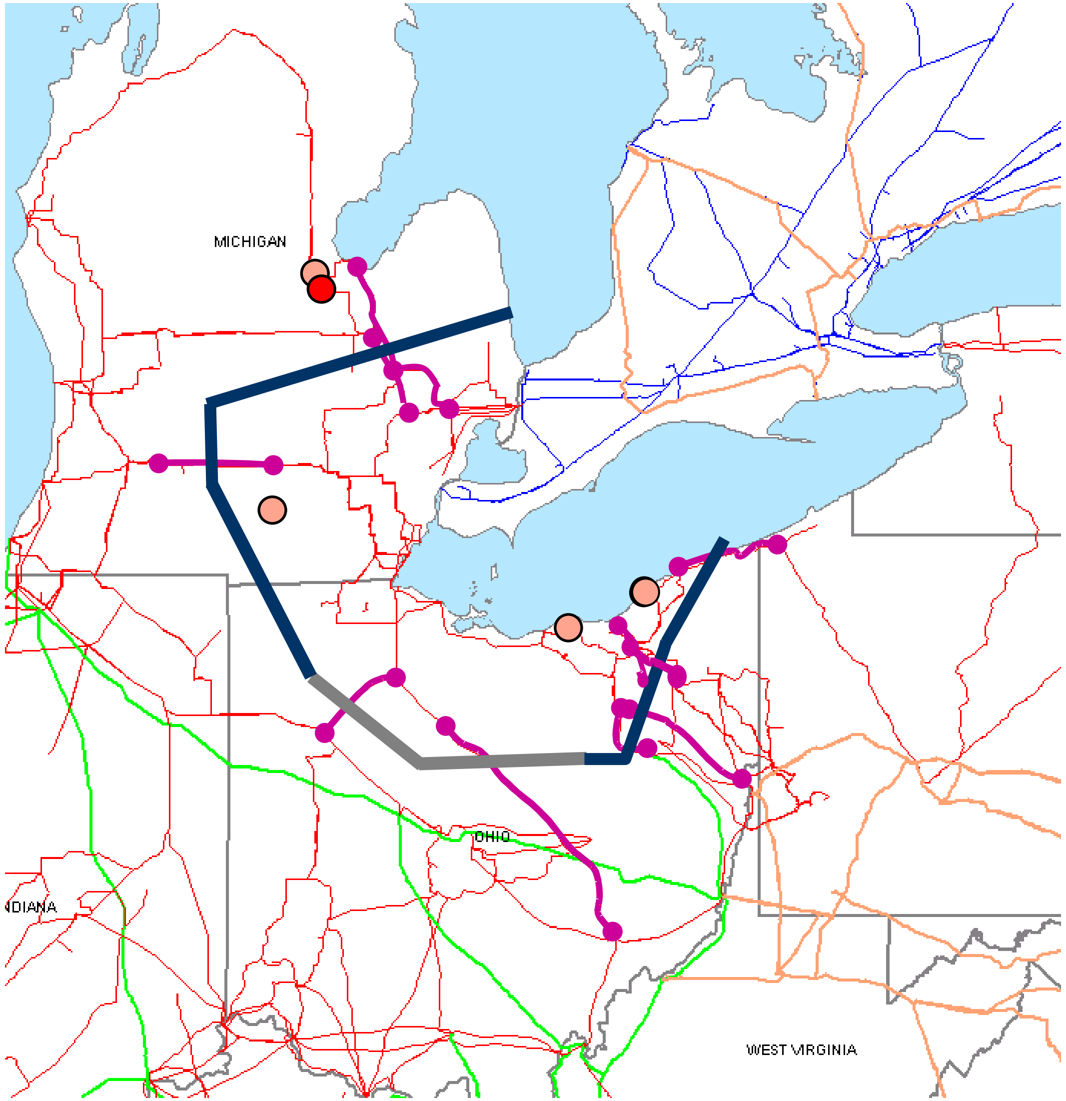


Image Source: August 14 2003 Blackout Final Report

Major Power Reversal: 16:10:38

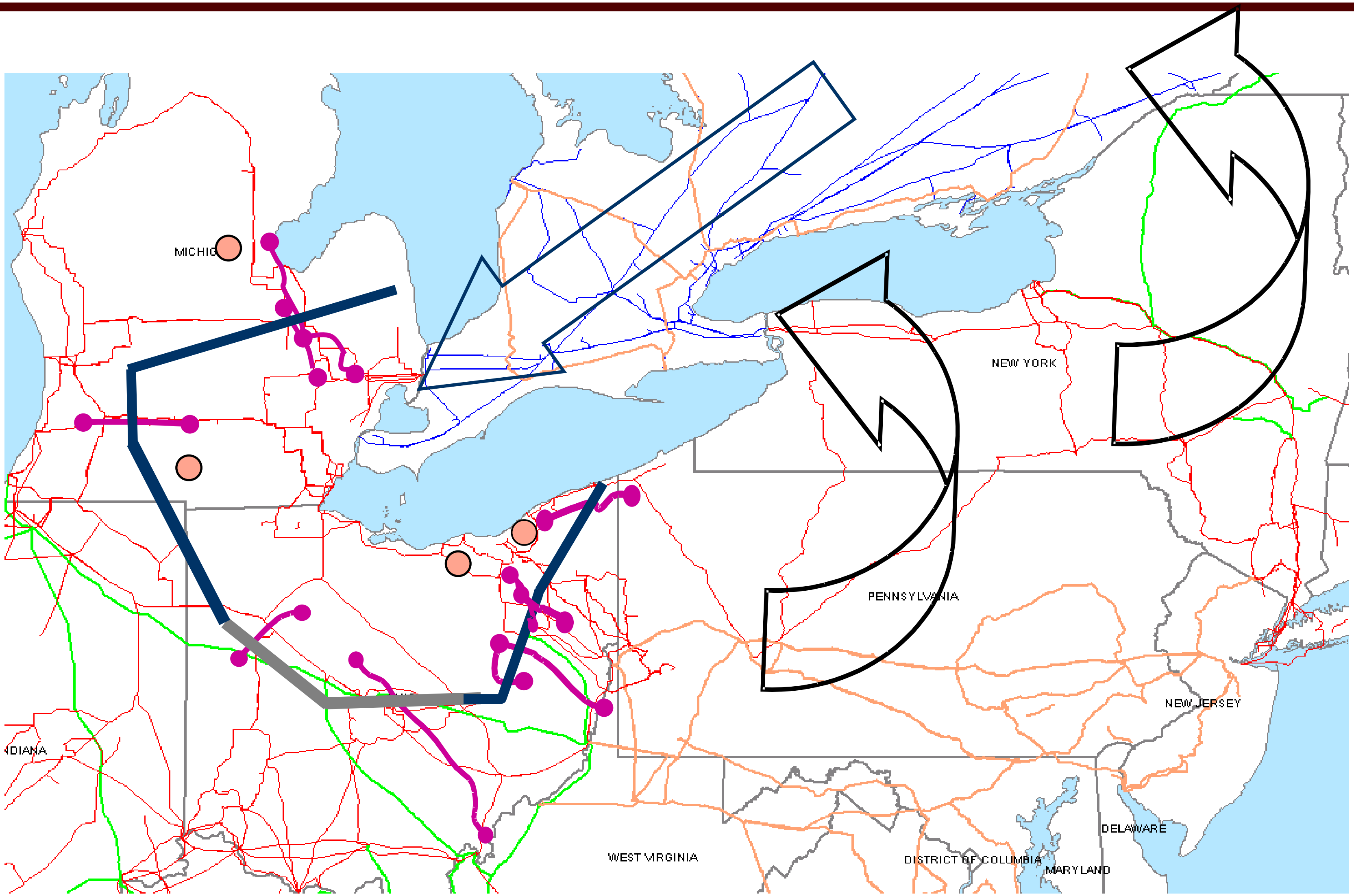


Image Source: August 14 2003 Blackout Final Report

Ontario/Michigan Interface Flows and Voltage

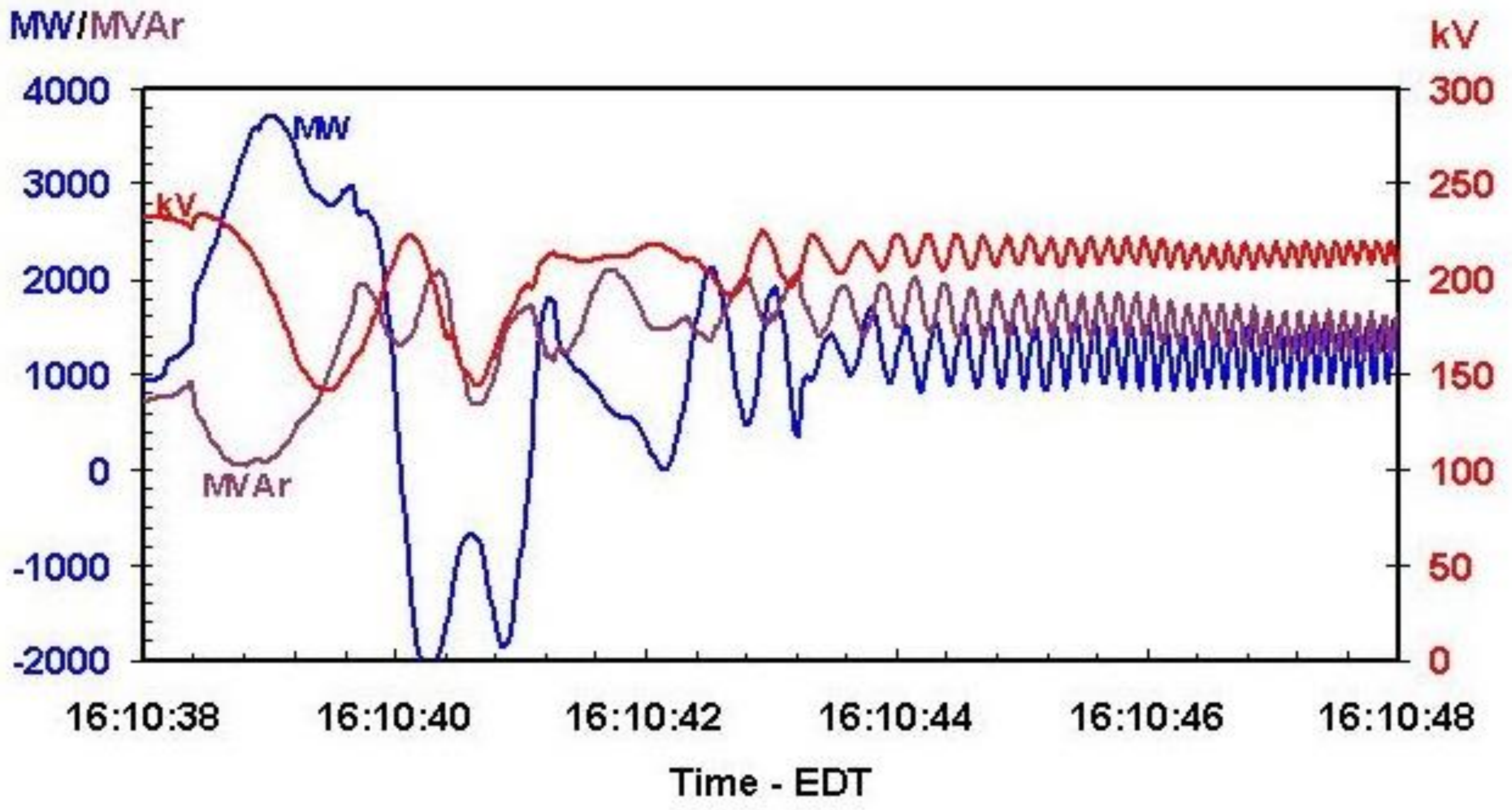


Image Source: August 14 2003 Blackout Final Report

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

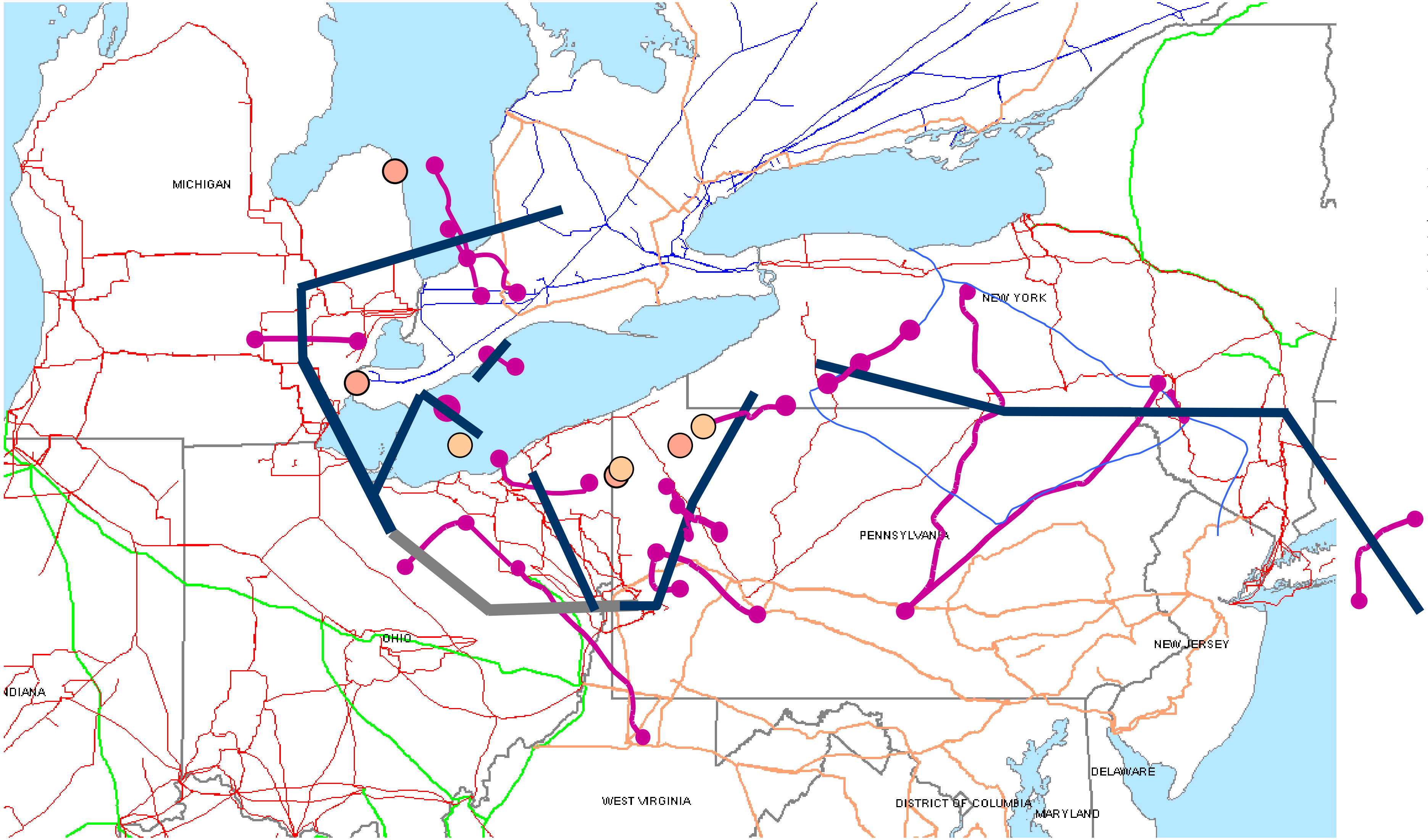


Image Source: August 14 2003 Blackout Final Report

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

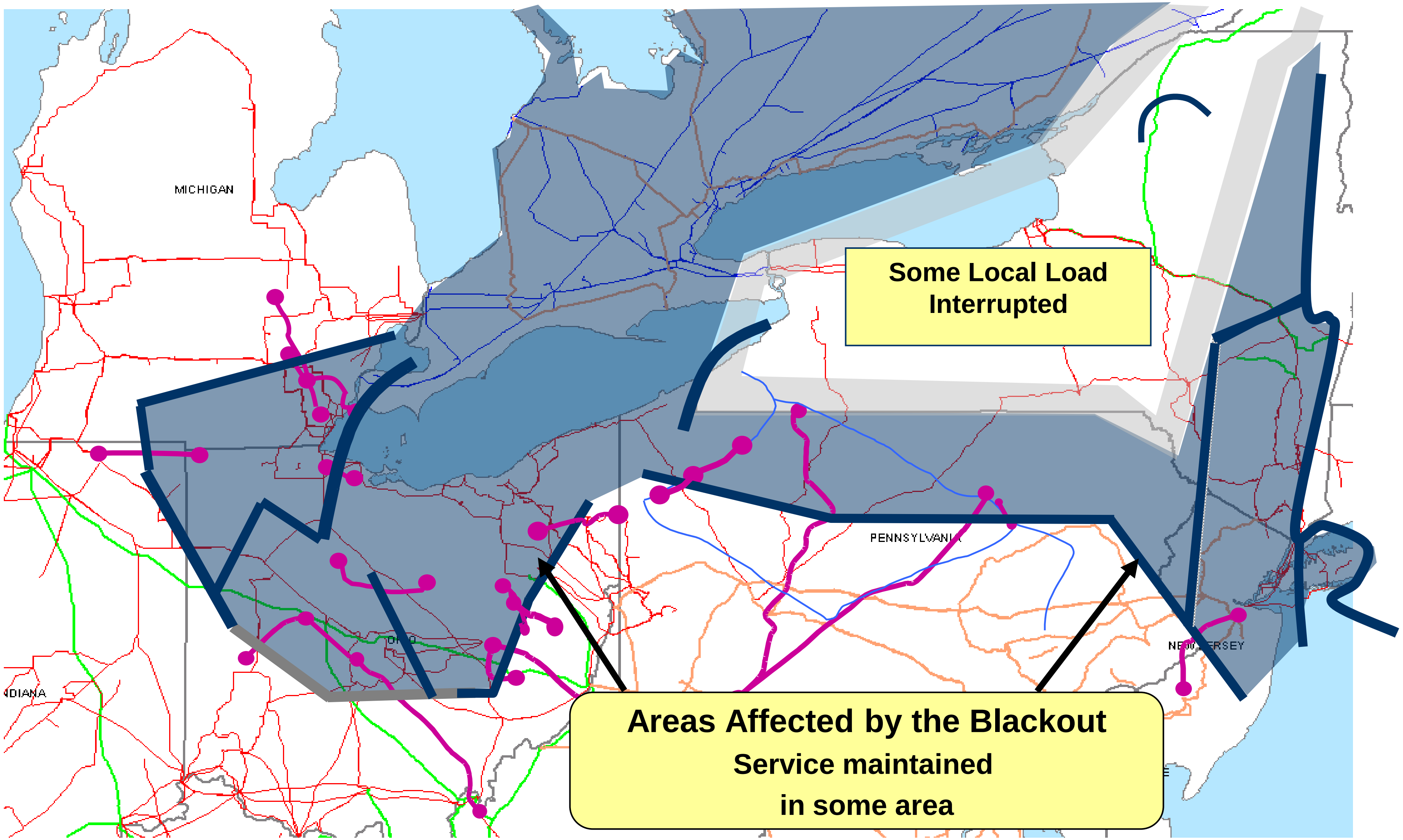


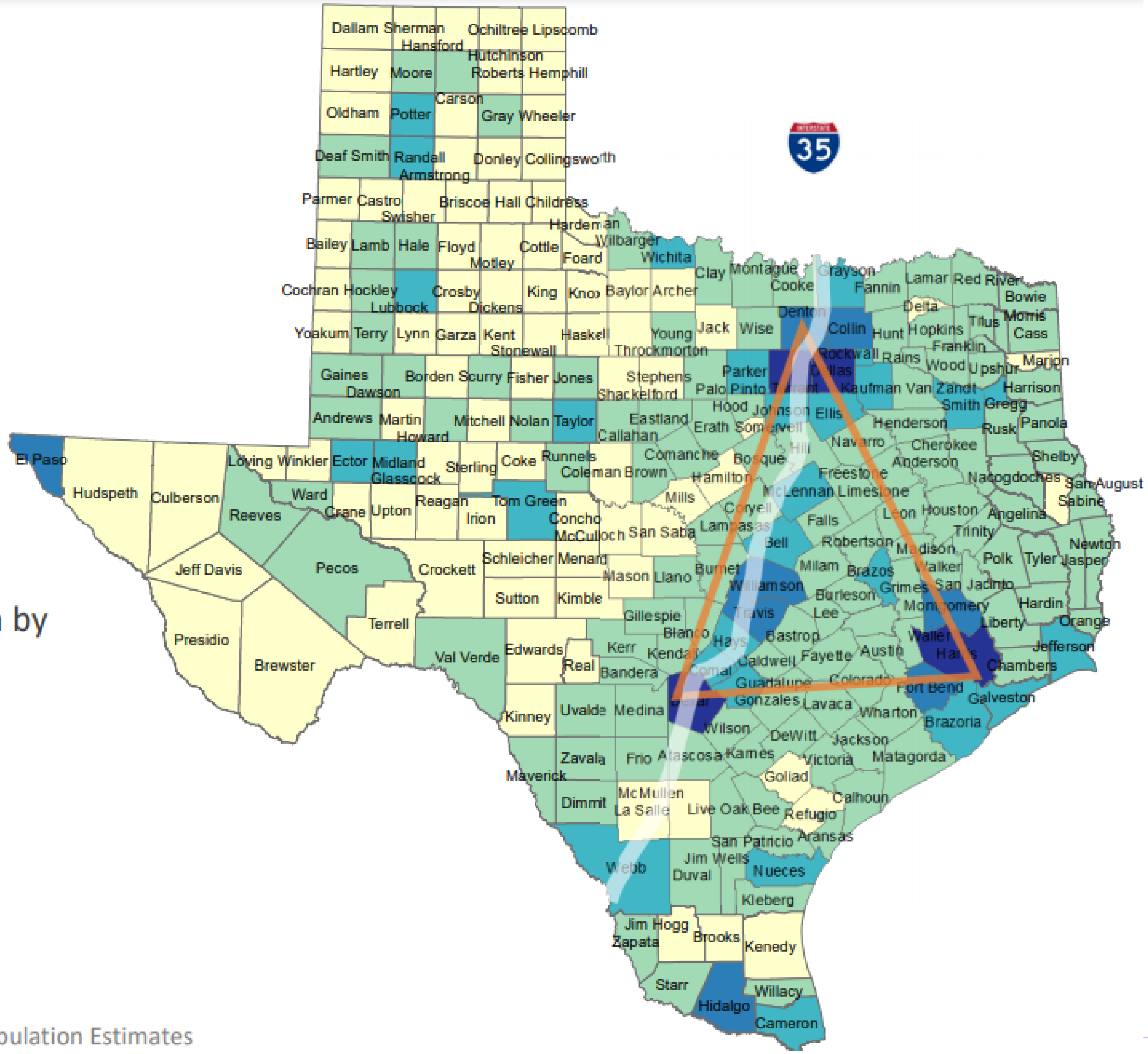
Image Source: August 14 2003 Blackout Final Report

Texas Near Blackout, February 2021

- Unfortunately, electric grids often make the news for all the wrong reasons!
- Starting on Feb 14, 2021 statewide Texas had temperatures much below avg., though not record cold
  - In College Station on Feb 15 is low was 9°F and very windy (and 5°F on Feb 16); avg. high is 65°F and low of 45°F
  - Our record low is -3°F (1/31/1949), our coldest February temperature was 5°F (2/5/1951) and last single digit was 9°F (12/22/1989)

- This stressed many infrastructures including the ERCOT electric grid

Texas Population Density



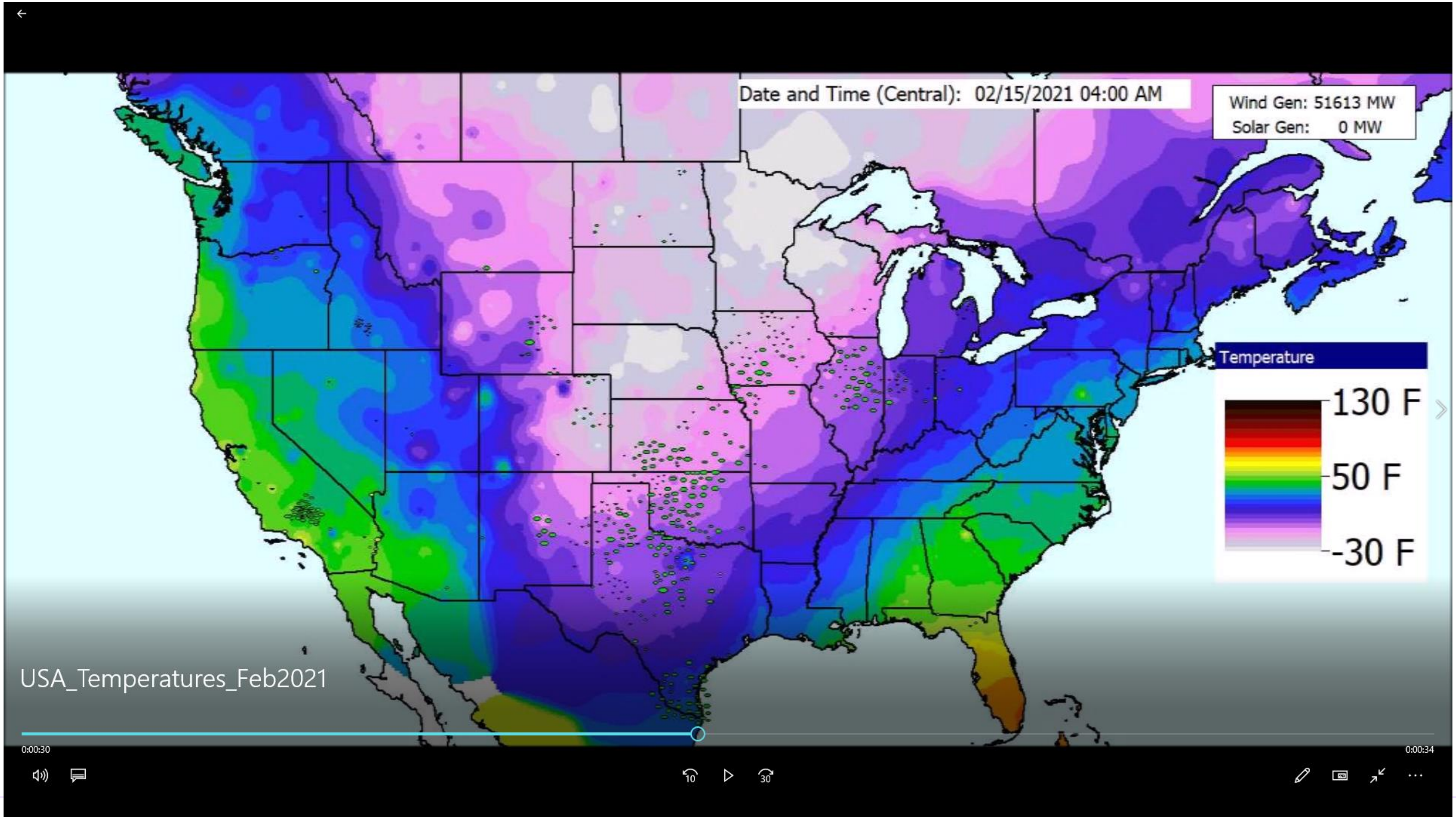
Total Estimated Population by County, 2019

(legend swatch)	169 - 10,000
(legend swatch)	10,001 - 100,000
(legend swatch)	100,001 - 500,000
(legend swatch)	5000,001 - 2,000,000
(legend swatch)	2,000,001 - 4,713,325

Source: U.S. Census Bureau, 2019 Population Estimates

85% of population is along or east of the I35 corridor (DFW to Waco to Austin to San Antonio to Laredo)

Visualization of Temperatures, Feb 11 to 18, 2021



ERCOT Generation Feb 11-18, 2021

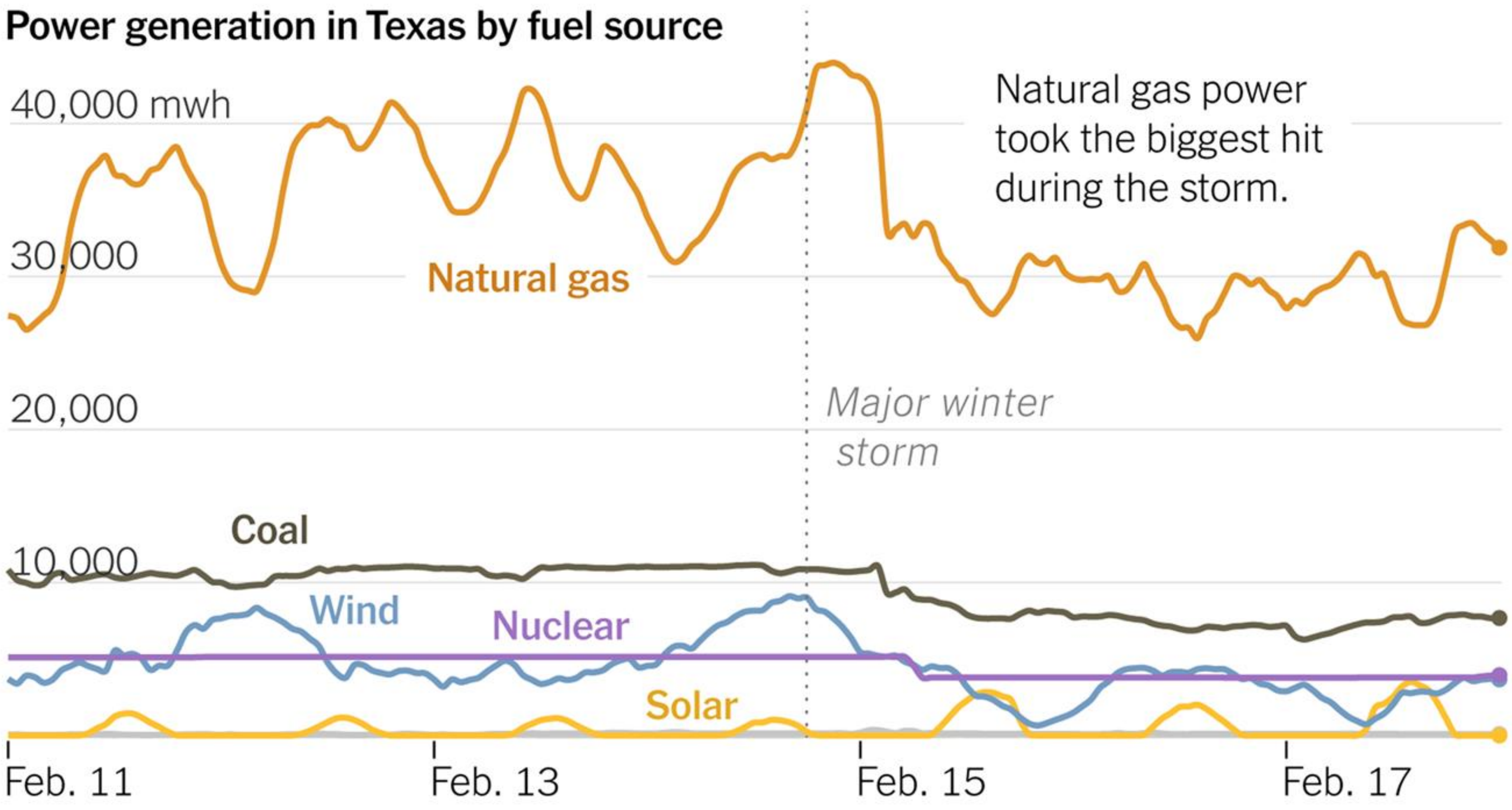
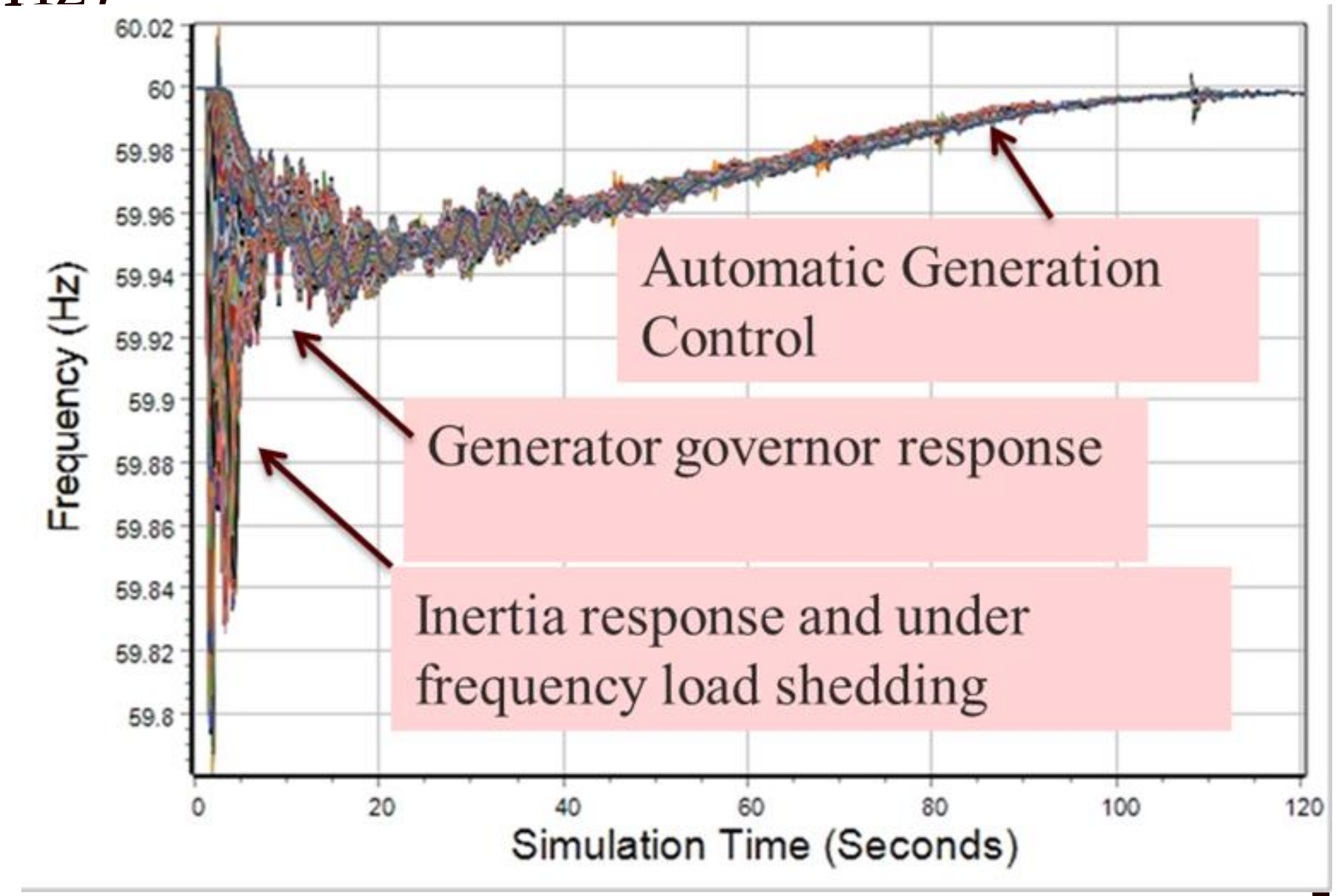


Image source: New York Times, Feb 23, 2021

Quick Aside: Power System Dynamic Response to Load/Gen Mismatch

- An electric grid frequency is constantly changing, but it usually within a few mHz of desired (e.g., 60 Hz)
- Too much generation increases the frequency and too little decreases it
- All grid elements have the same average frequency but during disturbances the frequency can oscillate



ERCOT Frequency, Feb 15, 2021

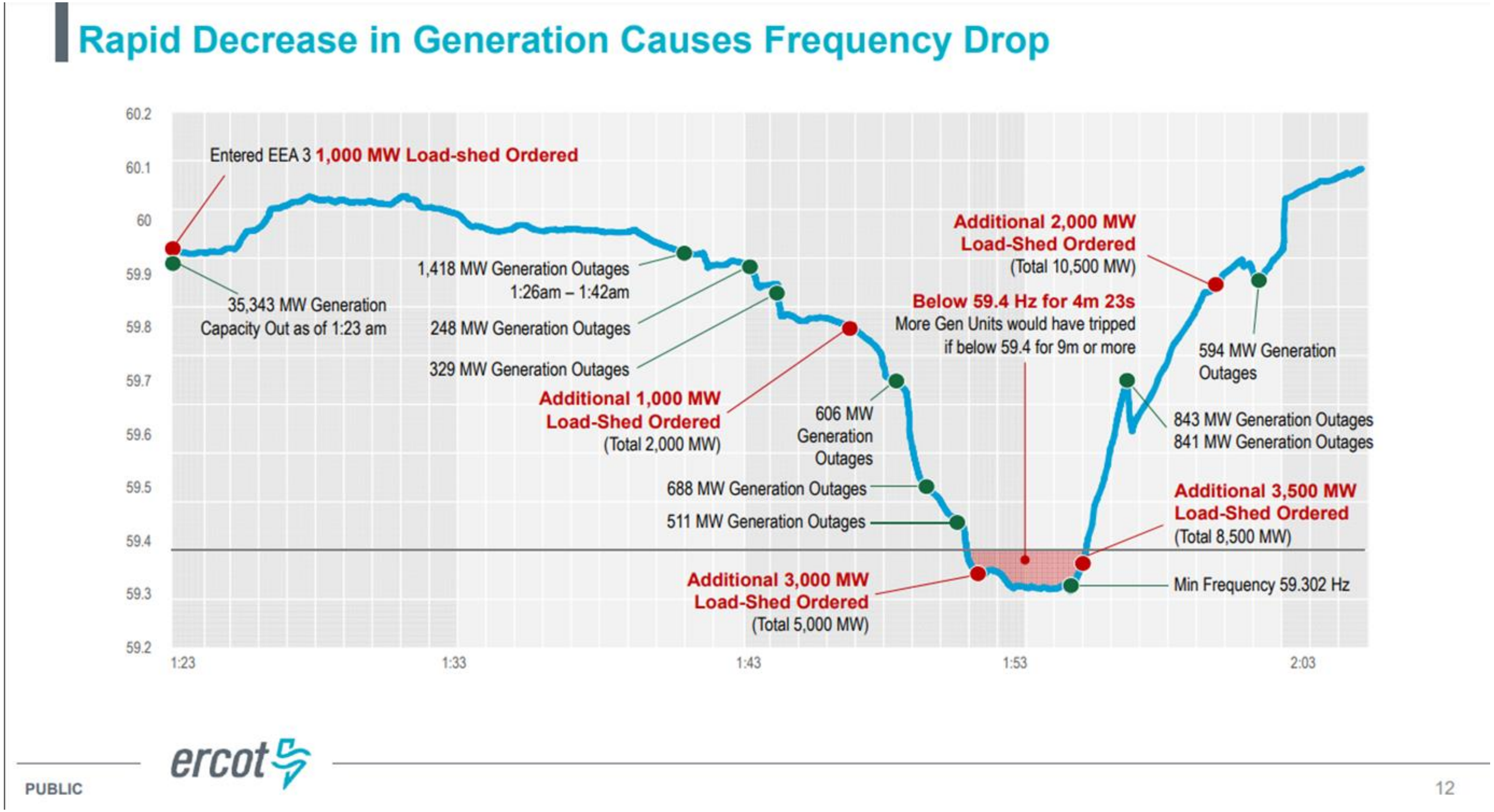
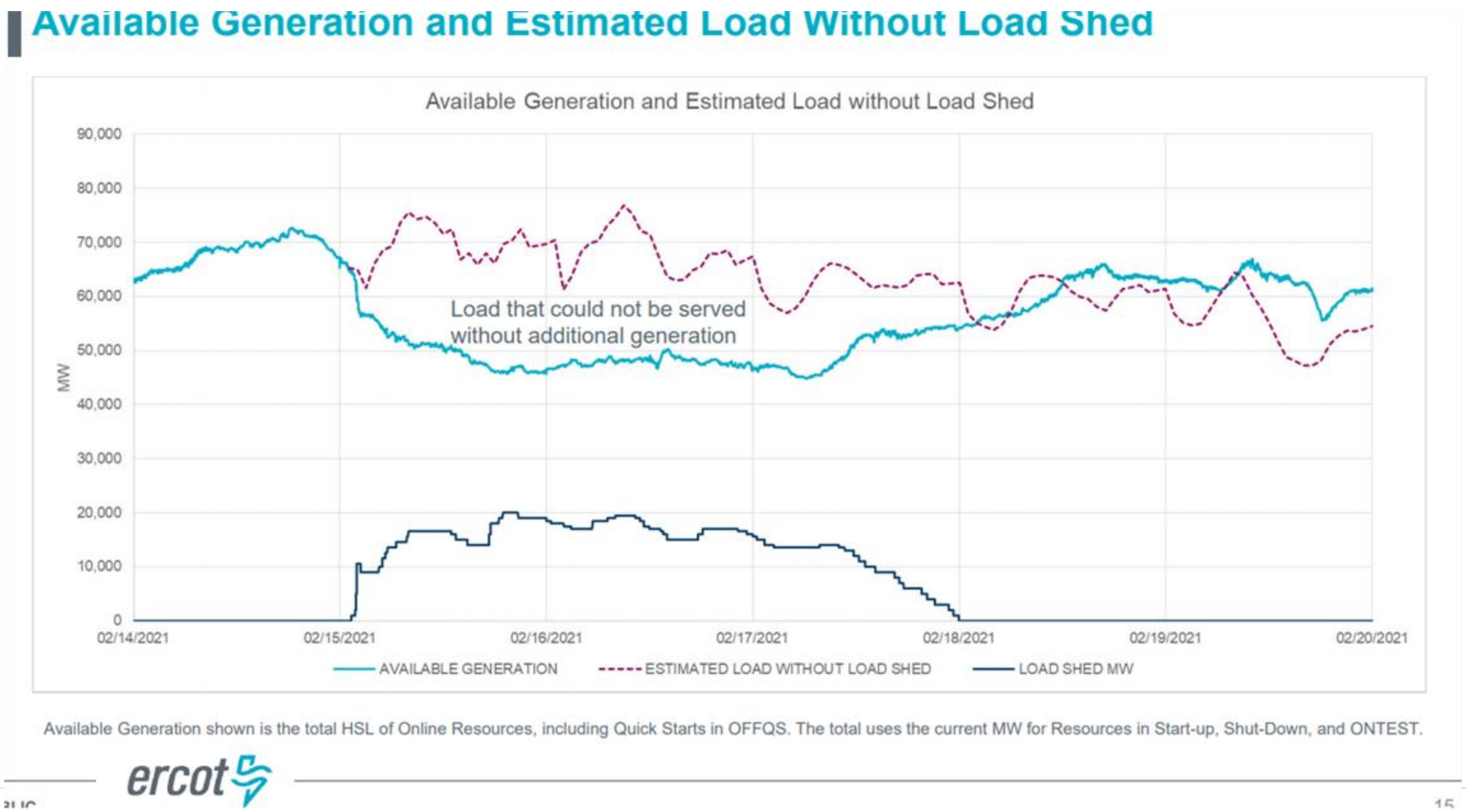


Image source: ERCOT Presentation by Bill Magness, February 25, 2021

ERCOT Load Shed and Rotating Blackouts

- The vast majority of the lost load was due to load shed and then rotating blackouts

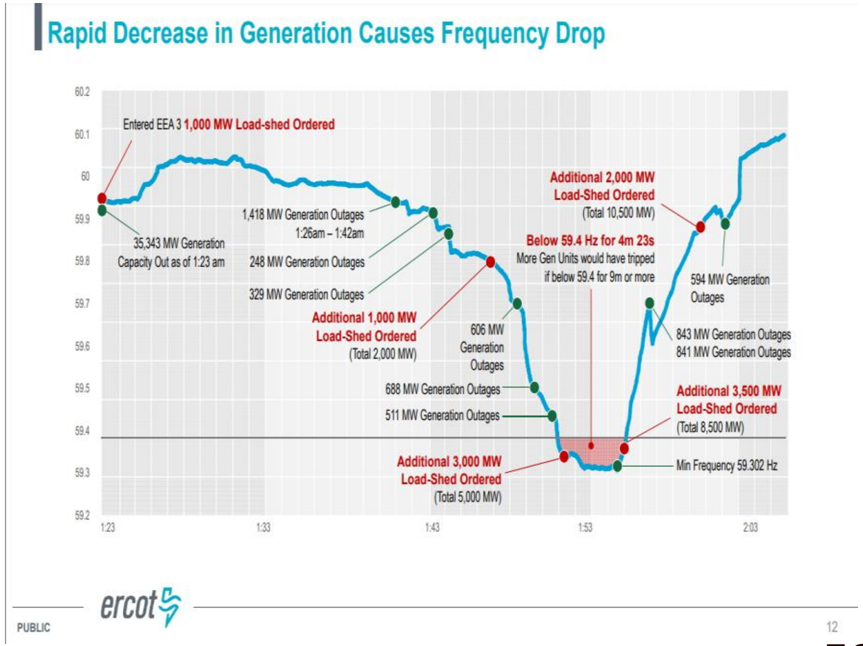


At the time the ERCOT peak load had been 74.8 GW (summer); winter peak of 69.2 GW was set on 2/14/21 (previous winter peak was 65.9 GW). A new winter peak of 80.6 GW was set in Feb 2025.

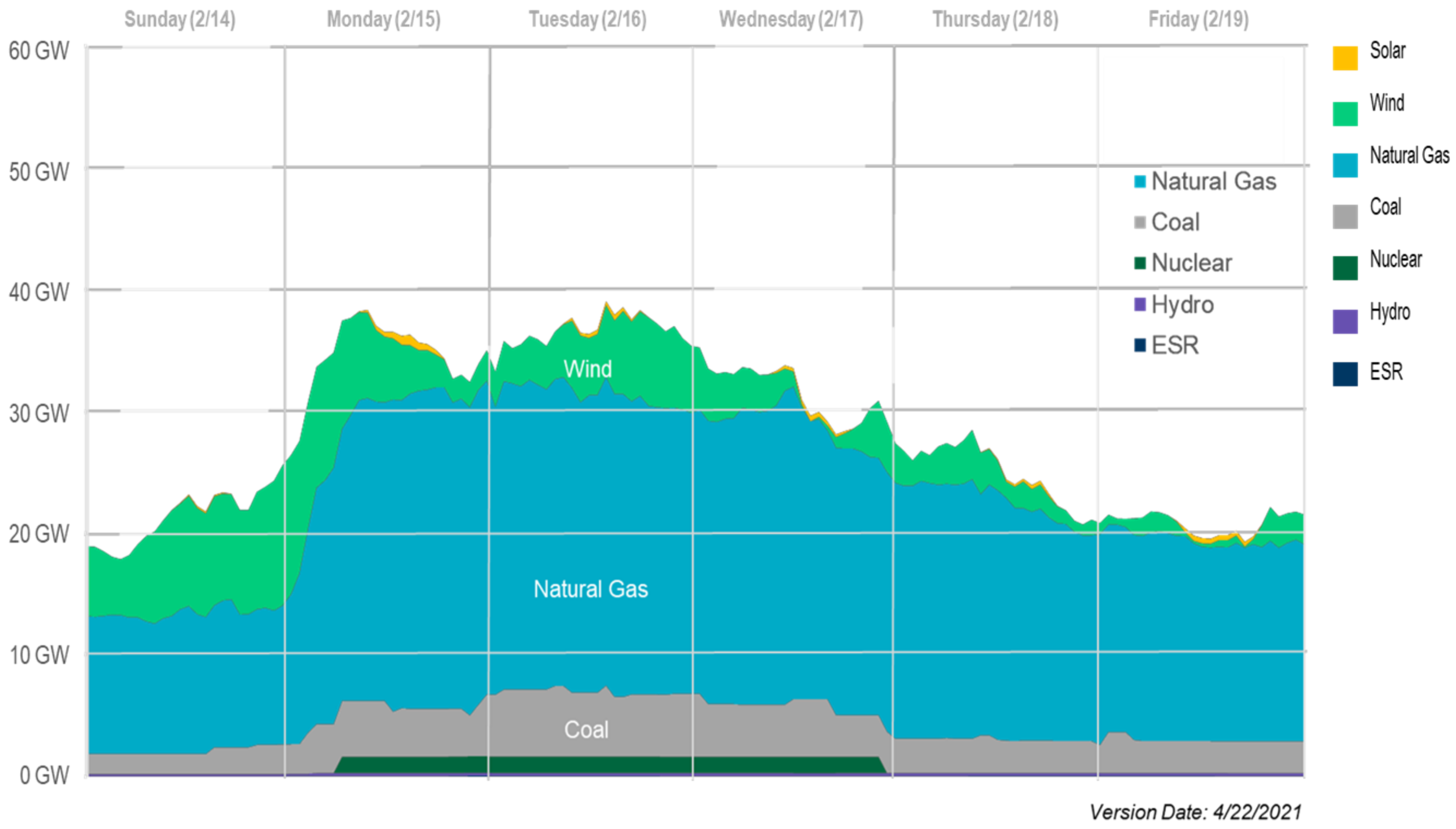
Image source: ERCOT Presentation by Bill Magness, February 25, 2021

How can Grids Cascade?

- ERCOT reported that they were minutes away from a catastrophic blackout that would have taken down the entire grid, requiring many days to restore
- Grids can cascade due to a number of different reasons with many related to the transmission grid flows and voltages
- For ERCOT the situation was the prolonged (minutes) low frequency would have result in generators tripping due to under frequency resulting in a cascading collapse in the frequency and hence the entire system



How Much Generation was Lost?



Wind and solar MW values based on estimated lost output due to outages and derates from slides 15 and 16.

This slide correctly recognizes that much of the wind capacity that was not available due to the cold, would not have been generating much because of low wind.

Winterizing Wind Turbines

- In general wind turbines can operate in quite low temperatures
- However, most of the wind turbines in Texas were not configured with the systems needed to deal with low temperatures
  - They mostly were not available because of turbine blade icing
- Wind turbines can be winterized with systems such as heated blades or coatings; packages can also be installed to protect the gearbox and motors, such as adding heating to the nacelle

Background: Why is ERCOT Separate?

- ERCOT operates asynchronous from the rest of North America, but has high voltage dc (HVDC) ties with the Eastern Interconnect and Mexico
- The advantage is ERCOT avoids some federal regulation. The legal basis for this is complex, based on the US Constitution, the Federal Power Act, the 5/4/76 midnight connection, other legislation, court rulings, and FERC decisions

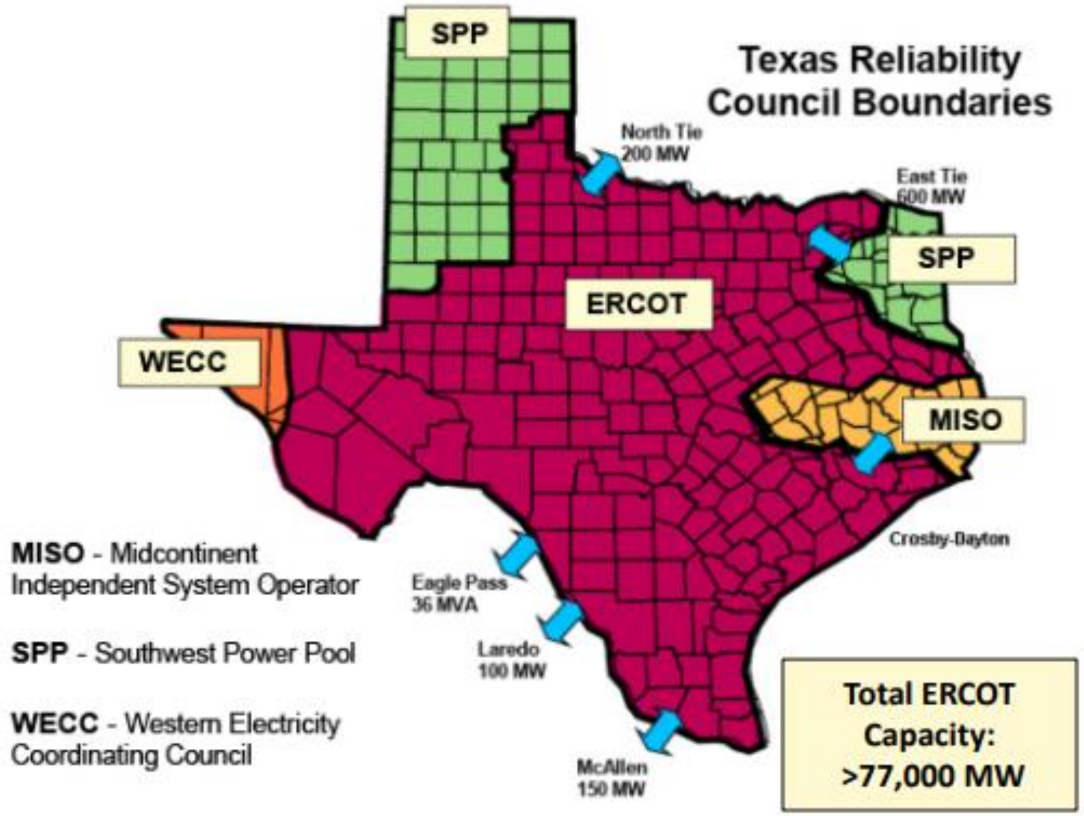
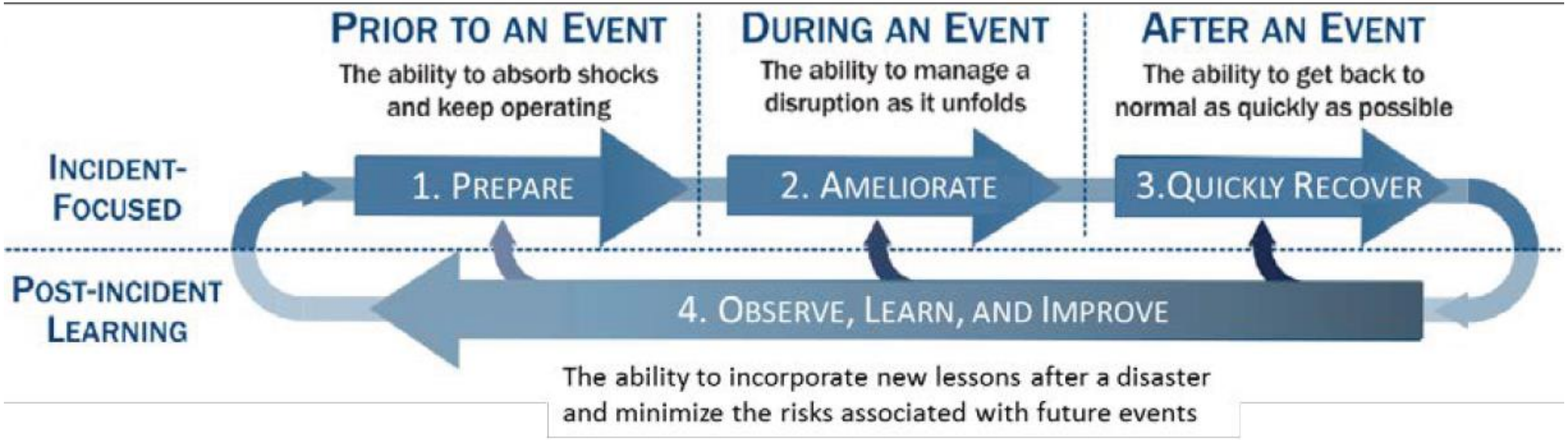


Image Source: aect.net/documents/2017/AECT%20LSB%20012617.pdf

General Grid Resilience: The Four Stage Process



This is presented as Figure 1.2a in the National Academies' *Enhancing the Resilience of the Nation's Electricity System* report (2017), and is originally from

S.E. Flynn, "America the resilient: Defying terrorism and mitigating natural disasters." *Foreign Affairs*, vol. 87: 2–8 (2008) and as illustrated by the National Infrastructure Advisory Council (NIAC) in 2010.