# The August 2003 Blackout

# 6.691 – Seminar in Electric Power Systems

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# Chapter 1: Introduction and Background

The blackout that occurred on August 14, 2003 in the Midwest regions of the United States and the province of Ontario in Canada was the worst in U.S. history.[1] It affected some 50 million people and an estimated electric load of 61,800 MW and it took as long as 4 days to restore power in some parts of the U.S.[2] In comparison, in the Northeast Blackout of 1965, only 25 million people were without power in New York state and New England,[1] and power was restored within 13 hours.[3] In the New York City Blackout of 1977, nine million people were affected,[1] and power was restored within 25 hours.[3] The August Blackout of 2003 affected greater number of people across a much wider geographical region including the states of Ohio, Michigan, Pennsylvania, New York, Vermont, Massachusetts, Connecticut, New Jersey, and the Canadian province of Ontario. This topic was of particular interest to the authors because it personally affected both of our lives. Some people say that they remember exactly where they were when Kennedy was shot or when the Challenger exploded, we both remember where we were when the lights went out in Michigan…..although it all started in Ohio.

## *Control Areas*

The sequence of events leading up to the cascade of power outages and the eventual August 2003 Blackout originated in the Cleveland-Akron area, which is under the control of FirstEnergy (FE). First Energy is composed of seven electric utility companies: Ohio Edison, The Illuminating Company, Toledo Edison, Penn Power, Penelec, Met-Ed, and Jersey Central Power & Light. FirstEnergy's service area is within a 500-mile radius of half of the United States' population.[4] Figure1 illustrate the geographic extent of FirstEnergy's operations.

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[1] http://www.cbsnews.com/stories/2003/08/15/national/main568422.shtml
[2] U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada," p. 1, April 2004.
[3] http://news.bbc.co.uk/1/hi/world/americas/3154757.stm
[4] http://www.firstenergycorp.com/engine?s=com.firstenergycorp.www.Home&p=%2FCorporate+Profile%2FIndex

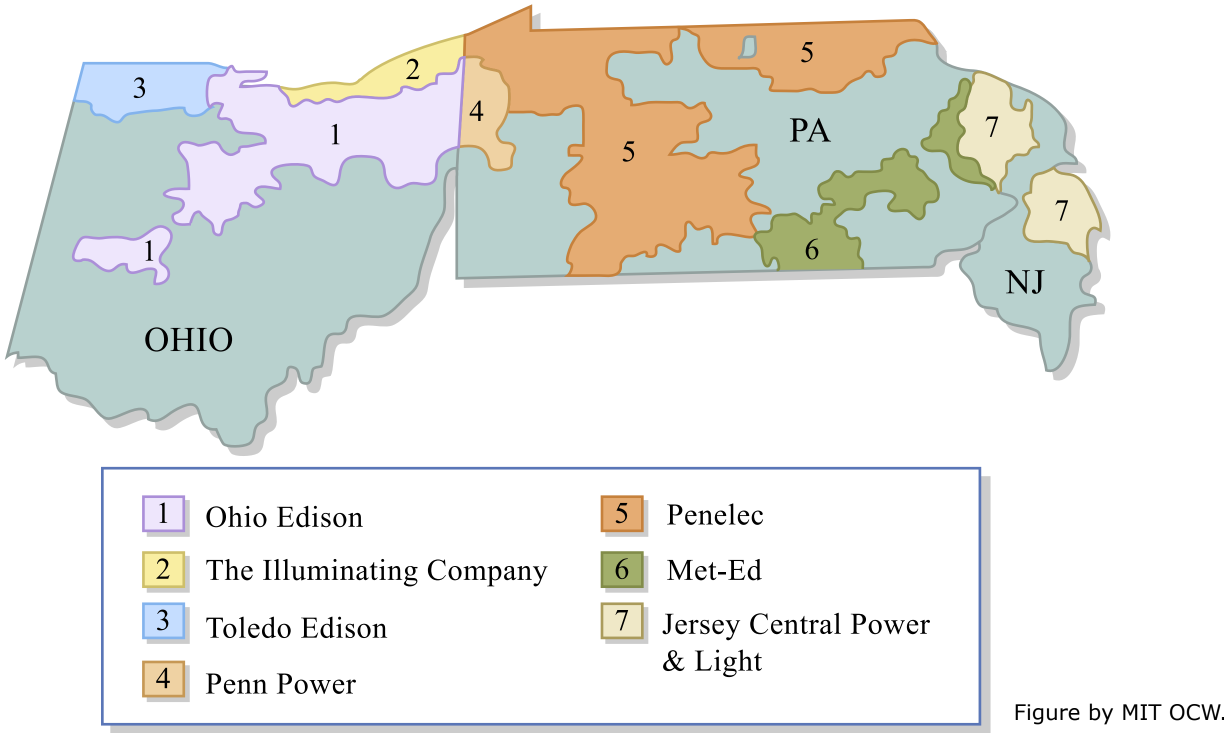


**Figure 1. First Energy's electric utilities and service areas.**[4]

American Electric Power (AEP) is a nearby control area that was also a key party involved in the events leading up to the cascade. AEP's area of control is also in Ohio and resides to the south of FirstEnergy. Control areas are responsible for real-time balancing of generation and loads to maintain a reliable system. Control areas are linked to each other, so in addition to maintaining stable operations in their native regions, they must also monitor interchanges and coordinate with other control areas to maintain reliable interconnections.[5]

## *RTOs and ISOs*

There are 140 such control areas across the U.S. and these control areas are generally defined and operated by one particular Regional Transmission Organization (RTO) or Independent System Operator (ISO). These independent entities were formed when deregulation split up generation, transmission, and distribution activities. The five RTOs/ISOs affected by the 2003 Blackout include MISO, PJM Connection, NYISO, ISO-NE, and IMO; however, only MISO and PJM were involved in the events leading up the cascade of outages. The geographic presence of these organizations is depicted in Figure 1. The responsibilities of the RTOs and ISOs are to implement the policies of the Energy Act of 1992 and manage current and next-day bulk system reliability and wholesale electricity markets. RTOs and ISOs do not own any transmission assets, may encompass one or more control area, are authorized by the Federal Energy Regulation Commission, and may be Reliability Coordinators (RCs).[5]

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[5] U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada," p. 11-14, April 2004.

### *Other Regulatory and Reliability Organizations*

The discussion of RTOs and ISOs brings up the topic of some other organizations that are involved in the operation and stability of the North American Power System. As such, we will give a brief overview of these entities and how they relate to each other. The Federal Energy Regulatory Commissions (FERC) is an independent regulatory agency within the United States Department of Energy. It has jurisdiction over interstate electricity sales, its decisions are not reviewed by the President or Congress, and it is self-funded through the industries that it regulates.[6]

NERC is the North American Electric Reliability Council which was formed by the electric utility industry in 1968 to promote the reliability and of the bulk power system in North America.[7] NERC is a voluntary non-government organization (NGO) that is composed of 10 regional reliability councils and is self-funded by these councils. The three regional councils involved in the blackout were ECAR (East Central Area), MAAC (Mid-Atlantic region), and NPCC (Northeast region). ECAR is the regional council that includes FirstEnergy and AEP where the events leading up to the cascade originated. [5] These councils are depicted below in Figure 2.

Reliability Coordinators (RCs) prepare reliability assessment and coordinate real-time emergency operations for one or more control areas. There are currently 18 reliability coordinators across the U.S. In the case of MISO and PJM, they have multiple control areas across many NERC regional councils which adds to the complexity of their responsibilities and control. MISO is FirstEnergy's RC and has responsibility for 37 control areas across four different regions. PJM, AEP's reliability coordinator, is responsible for nine control areas across three different regions. The other RCs affected by the blackout—NYISO, ISO-NE, and IMO—are only responsible for one or two control areas contained in one NERC region.[5]

[6] Wikipedia Dictionary, http://en.wikipedia.org/wiki/FERC
[7] Wikipedia Dictionary, http://en.wikipedia.org/wiki/North_American_Electric_Reliability_Council

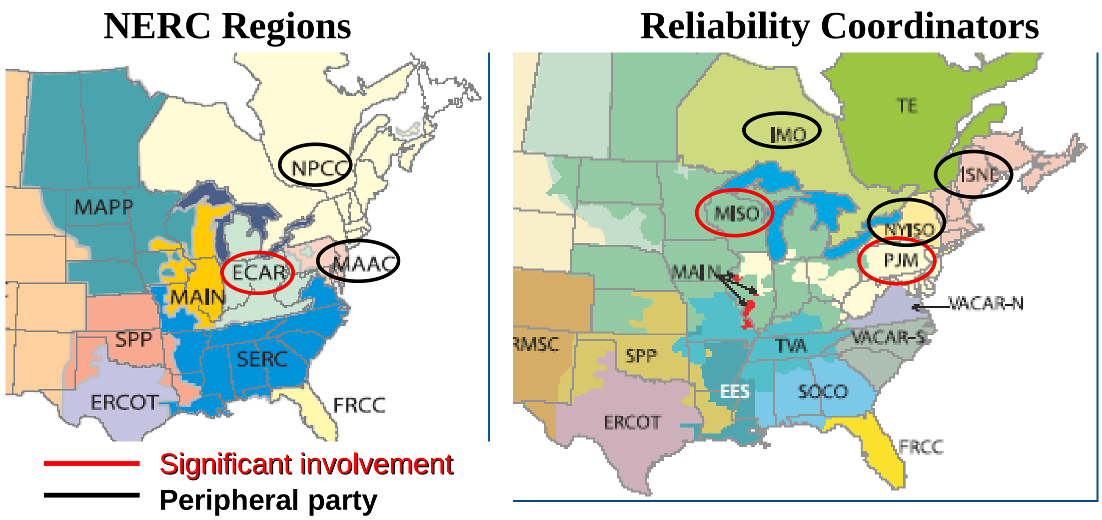


**Figure 2. NERC Regions and Reliability Coordinators affected by 2003 Blackout.** [5]

## Chapter 2: Evaluating Causes and Factors of the Blackout

Many different factors were identified as potential direct causes or contributing factors of the August 2003 Blackout. For example, one factor that was believed to be a direct cause of the Blackout, power transfer into and across the Midwest, was found to be neither a cause nor a contributing factor to the blackout. Other factors that were also considered as causes or contributing factors to the Blackout include daily high temperatures, under-forecasted loads, unavailable resources, voltage levels and criteria, and abnormal system frequencies. In addition, we cited some other factors that seem to have contributed to the Blackout, but were not considered to be actual causes of the Blackout. Based upon the evaluation of all of these potential, contributing factors, the four major causes of the Blackout that were identified by the U.S.-Canada Power System Outage Task Force will be presented at the end of this chapter.

### *High August Temperatures*

Temperatures in the Midwest rose during the period from August 11th – August 14th, reaching temperatures above the normal daily highs for August. In Akron, a major city in FE's control area, temperatures started at normal August highs of 78˚F and reached a high of 88˚F on August 14. This trend created a 20% increase in peak load for FE over these four days. Although higher loads had previously been handled by other control areas in the Midwest, the peak load on August 14th was the highest load that FirstEnergy experienced for all of 2003. Although these temperatures were above average daily highs, they were well within a normal range on August 14th and not even close to record highs that had been seen for that area in the past. *As a result, while the temperatures leading up to and occurring on August 14th were not a cause of the Blackout, they were a contributing factor to the events leading up the cascade of outages.*[8]

As mentioned earlier, the control area RTOs and ISOs forecast energy demands for next-day service. Taking into account the outside air temperatures discussed above, is one input into this forecasting process. During the period from August 11th – August 14th, several large

[8] U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada," p. 25, April 2004.

operators in the Midwest consistently under-forecasted load demands.[8] This was most likely a direct result of the increased air conditioner usage that came about due to the persistent, above-average daily temperatures. Since air conditioners are induction motors and have lower power factors, they consume more reactive power than most other consumer electric devices. This is an important point that will become more relevant in the Voltage Criteria and Reserves section. *While these under-forecasted loads, like temperatures, were classified as contributing factors, they did not cause the Blackout.*

## *Unavailable Resources*

Temperatures and load forecasts are important in evaluating system performance and stability based upon the available resources. For example, you wouldn't schedule planned equipment service during periods of peak demand, unless it is unavoidable. Also, once you see what loads are expected for the next day, it is important to take note of all of the resources—transmission lines, capacitor banks, generation units, etc.—that are available and all that are off-line for planned or unplanned reasons. When evaluating the safe operating levels for August 14th, FirstEnergy knew that the generators shown in Figure 3 would not be available:

| Generator | Rating | Reason |
|---|---|---|
| Davis-Besse Nuclear Unit | 883 MW | Prolonged NRC-ordered outage beginning on 3/22/02 |
| Sammis Unit 3 | 180 MW | Forced outage on 8/12/03 |
| Eastlake Unit 4 | 238 MW | Forced outage on 8/13/03 |
| Monroe Unit 1 | 817 MW | Planned outage, taken out of service on 8/8/03 |
| Cook Nuclear Unit 2 | 1,060 MW | Outage began on 8/13/03 |

**Figure 3. Unavailable Generators heading into August 14th.[9]**

On August 13th, FirstEnergy determined that the security of the system would not be compromised as a result of these generators being off-line. *Post-blackout analysis also verified that these generators did not cause the blackout.*[9]

In addition to resources that were off-line prior to August 14th, three more sets of resources became unavailable on August 14th. First, several Cinergy transmission lines and the 345-kV Stuart-Atlantic line operated by DPL were down on August 14th. While these lines were not directly problematic for FE's system, FE was not aware of the status of these lines, which

[9] Ibid, p. 26-43.

presented anomalies to their state estimator and created confusion for FE's operators.  Second, four or five capacitor banks were taken off-line for inspection.  These capacitor banks had not been identified as vital resources by FE, although they should have.  When considering the high load demands leading up to and continuing on August 14th, had they been identified as vital resources, they would not have been taken off-line.  Finally, the Eastlake Unit 5 generator went down unexpectedly on August 14th.  *None of these conditions was considered to be a cause of the Blackout; however, the lack of reactive power supplied by the capacitor bank and the loss of the Eastlake generating unit made it more difficult to safely maintain and operate the FE power system.*[9]

## *Voltage Criteria and Reserves*

As noted above, with some key resources being off-line, the voltage criteria and reserves that FirstEnergy operated under became even more important on August 14th and thus were evaluated as potential causes of the Blackout.  FirstEnergy set the low end of their voltage criteria at 90% of rated voltage, this was the lowest safe operating limit established by any operator or RC in the region,[9] so it became a suspected culprit for the blackout.  In addition, the Cleveland-Akron area of FirstEnergy had the lowest available reactive power capacity and, as a result, the lowest reactive power reserves on August 14th of all control areas in the region.[9] Figure 4 shows the stark contrast in reactive power capacity and reserves between the various control areas in.  Unfortunately, since reactive power cannot be distributed over great distance, the excess reactive power that surrounding control areas had on August 14th, could not be used to alleviate FE's Cleveland-Akron reactive power shortage.  *It was determined by the U.S.-Canada task force that these low reactive voltage reserves were a contributing factor to the Blackout, but, again, not a direct cause.*[9]

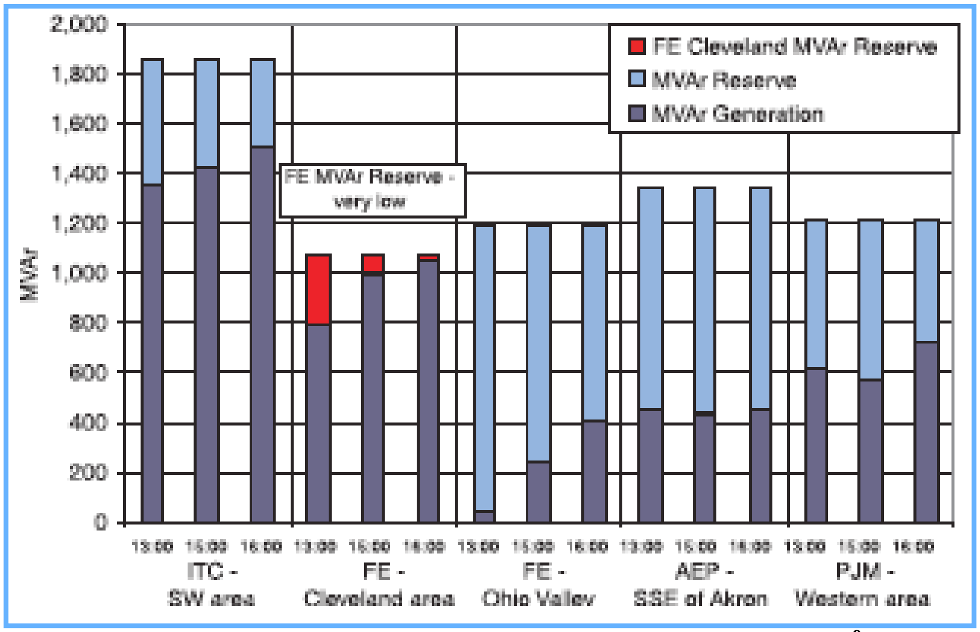


**Figure 4. Reactive Reserves in Michigan and Ohio on August 14.**[9]

## *System Frequencies and Power Transfers*

System frequencies and power transfers were also considered as potential contributing factors to or causes of the Blackout. When they were evaluated, however, they were found to be within normal ranges. Normal system frequencies should be in the range of 59.95 – 60.05 Hz. Up until the start of the Blackout, frequencies never exceeded 59.94 – 60.06 Hz which is fine for the system. Similarly, power transfers in the Midwest were within normal ranges. In fact, up to and including the time at which the last of FE's 345-kV lines locked out and triggered the Blackout, the majority of the load being carried on FE's lines was attributed to demand from the native region.[9] This means that there weren't excessive power transfers or loads going to neighboring regions that could be blamed for the Blackout. *In summary, neither abnormal system frequencies nor excessive power transfers occurred on August 14th before the cascade. Therefore, these two factors are neither contributing factors nor causes of the Blackout.*

## *Four Major Causes of the Blackout*

With all of these factors being considered, analysis of pre-cascade conditions performed, and a re-building of the events and actions leading up to the start of the cascade, the U.S.-Canada Task Force determined the four major root causes of the Blackout. These causes were all attributable to human factors, policies, and lack of action, rather than specific conditions. The four major causes are as follows:[10]

1. *Inadequate system understanding* by ECAR and FirstEnergy of the weaknesses and dynamics of the Cleveland-Akron portion of FirstEnergy's system. This includes identifying vital operating resources and performing sufficient contingency analyses.
2. *Inadequate situational awareness* meaning that FirstEnergy didn't recognize or comprehend the deteriorating condition of its power system on August 14th.
3. *Inadequate tree trimming* by FirstEnergy in the rights of way of their transmission lines.
4. *Inadequate diagnostic support on the part of the reliability coordinators* because they were not using real-time data to provide diagnostic support.

These causes will become apparent in subsequent chapters as the pre-cascade sequence of events and the violations in NERC policies are identified.

[10] Ibid, p. 18.

# Chapter 3: Pre-Cascade Events & Contingency Violations

The sequence of events leading up to the cascade, including the series of power system mishaps and conflicting information received by FirstEnergy's control room operators, is almost as interesting as the effects of the cascade itself. The pre-cascade events played out in four phases: (1) a normal afternoon degrades, (2) FirstEnergy experiences computer failures, (3) three 345-kV lines go down, and (4) sixteen of FE's 138-kV lines fail, followed by 345-kV Sammis-Star line which triggered the Blackout cascade.

## *Phase 1: A Normal Afternoon Degrades*

The first significant event occurred when MISO's state estimator encountered an anomaly at 12:15 which was triggered by Cinergy's lines in Indiana which were taken off-line without MISO being notified. The state estimator (SE) was shut down for troubleshooting, and was not again available for use until 16:04, minutes before the cascade started. The state estimator (SE) is designed to look at the power system and constantly perform checks, if it doesn't see what it expects to, based upon shorted lines or lines that are out of service unbeknownst to the SE, it will fail the check. The state estimator is also an important tool in performing contingency analyses, so when the second event occurred, loss of FirstEnergy's Eastlake Unit 5 generator, FirstEnergy was not able to perform an N-1 contingency analysis. If they had been able to they would have realized the dire consequences of losing a major transmission line in their system.

The third event in this phase was the loss of the 345-kV Stuart-Atlantic line at 14:02, which didn't affect FE's power system, but further slowed down the process of sorting out data and getting the SE back to normal operating conditions.[11]

## *Phase 2: FirstEnergy Computer Failures*

During the time period from 14:14 to 14:59, FirstEnergy encountered a series of computer failures in their control room. First, at 14:14, FE's control room alarm system went down unbeknownst to control room operators or IT personnel and this problem was not

[11] Ibid p. 45-48.

recognized until 14:41. As a result, FE control room operators weren't being notified of any problems with the power grid by their computers. In the period from 14:20 to 14:54, several failures occurred with FE's emergency monitoring system which would have detected unsafe operating systems or excessively high ratings on their system. The only notification of power system problems they received at this time was a phone call from neighboring AEP about the Star-South Canton line that tripped and then re-closed. FirstEnergy didn't show a record of it in their system so they dismissed the incident. [12]

## *Phase 3: Loss of Three 345-kV Lines*

Three of FE's major 345-kV lines tripped and locked out between 15:05 and 15:41. Each of these failures occurred due to hitting an overgrown tree that should have been trimmed, not due to sag from excessive line loads and high conductor temperatures.

- At 15:05, the Harding-Chamberlain locked out at 44% or its emergency rating. There was no evidence that FirstEnergy or its reliability coordinator, MISO, knew of the Harding-Chamberlain line failure until after the Blackout.
- At 15:32, the Hanna-Juniper contacted a tree and locked out at 88% of its emergency rating. Tree trimming crews saw the Hanna-Juniper line contact the tree; however, they reported it as the Eastlake-Juniper line so FE had difficulty in making sense of this report.
- At 15:35 and 15:36, AEP contacted reliability coordinator PJM, and MISO contacted FE, regarding contingency analyses for the loss of the Hanna-Juniper line; none of these parties knew at this time that Hanna-Juniper was already lost.
- At 15:41, the Star-South Canton failed at 93% of its rating. The Star-South Canton line was the only one that managed to re-close twice after tripping, and before finally locking out on the third contact. At this point in time, PJM and AEP were still discussing transmission loading relief for the Hanna-Juniper line.[13]

## *Phase 4: Loss of 138-kV Lines and Sammis-Star 345-kV Line*

At 15:39, the first of sixteen 138-kV lines in FirstEnergy's system began to trip and lockout due to line sag and other faults. At 16:06, the Sammis-Star line tripped and triggered the

[12] Ibid p. 52-56.
[13] Ibid p. 57-63.

cascade which led to the Blackout. The Sammis-Star line, unlike the other 345-kV lines that failed, tripped due to a low apparent impedance—low voltage coupled with high current in the line.[14]

## *Preventive Measures and Contingency Violations*

Several steps could have been taken to prevent the Sammis-Star line from failing and creating the cascade. In theory, had one of the three 345-kV lines (Harding-Chamberlain, Hanna-Juniper, or Star-South Canton) been restored, some of the 138-kV lines would have been saved. Furthermore, had two of these three 345-kV lines been restored, none of the 138-kV lines would have failed and the subsequent failure of the Sammis-Star line and the Blackout itself wouldn't have occurred. In reality, since the Harding-Chamberlain, Hanna-Juniper, and Star-South Canton lines all tripped because of tree contact, it is not likely that they could have been fixed in time—even if FirstEnergy had been fully aware of the situation at hand. The only feasible solution to save the Sammis-Star line and prevent the Blackout would have been to shed 1,500 MW of the Cleveland-Akron load prior to 16:06 when Sammis-Star tripped.[14,12]

Up until the Harding-Chamberlain (H-C) line failed at 15:05, there were no contingency violations on the part of MISO or FirstEnergy. After the H-C loss, two contingency analyses should have been performed for remaining key resources because the system was in an N-2 condition. The first of these would have been for the 345-kV Star-Juniper line in the event that the Hanna-Juniper line was lost. The second, a contingency analysis for both the Hanna-Juniper and Harding-Juniper lines if the Perry generation plant went down. However, given that FE and MISO were not aware that H-C was down, no contingency analyses were performed.[14,12]

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[14] Ibid p. 64-70.

# Chapter 4: Cascade Stage of the Blackout

Chapter 3 described the events that set the stage for the August 2003 blackout. The massive blackout could have been averted prior to the tripping of the Sammis-Star 345-kV. However, once the Sammis-Star line was lost, a cascade of interruptions was set in motion. The full cascade happened in three phases: 1) the cascade in Northern Ohio and South Central Michigan, 2) the full cascade, and 3) the forming of electrical islands parts of the Midwest and Northeast.

***The cascade in Northern Ohio and South Central Michigan.***

The collapse of FirstEnergy's transmission system caused unplanned power shifts across the region which in turn caused zone 3 impedance relays to operate under emergency conditions rather than actual fault conditions.[15] The abnormally low voltage conditions in Northern Ohio coupled with power swings in the system due to events before the Sammis-Star line trip appeared as fault conditions to the zone 3 relays causing lines to trip and exacerbating the problem.

***The full cascade.***

The power surges from neighboring areas caused more zone 3 impedance relays to operate. Western Ohio was separated from the east, Michigan was separated into east and west causing a power flow reversal within Michigan towards Cleveland. This power was supplied from Ontario and further upstream from New York. Lines in New York saw this power surge as a fault and tripped containing the cascade from spreading further east. The only power lines left supplying Ontario from the west then became overloaded and soon tripped containing the cascade from spreading further west.

***The forming of electrical islands.***

With much of the Midwest, Northeast and Ontario separated into electrical islands the load and generation had to be balanced locally. The islands could not balance the power flow

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[15] Impedance relays measure the apparent impedance ($Z=V/I$) of the line. There are three zones that impedance relays monitor. Zone 1 relays look for faults over 80% of the line connected directly to the relay, and trips immediately when the apparent impedance falls below the specified set point. Zone 2 relays monitor the entire line and slightly beyond and operate when the apparent impedance falls below the set point for a specified amount of time. Zone 3 relays are similar to zone 2 relays except that they look for faults further away and operate more slowly (after a longer delay), but should trip only during a fault condition and not under typical emergency conditions.

quickly enough; the system was dynamically unstable. The severe power swings and the inability of the islands to balance power flow caused blackouts in each of those islands.

## *Phase 5: The cascade in Northern Ohio and South Central Michigan.*

The cascade in Northern Ohio and South Central Michigan is summarized in the following timeline:

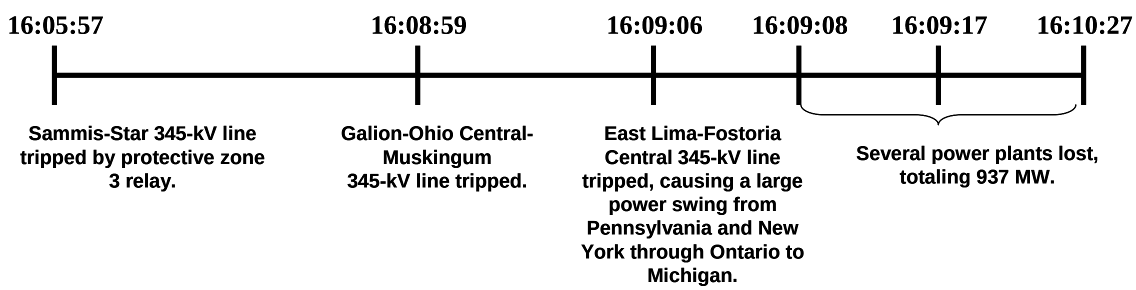


**Figure 5. Timeline of the cascade in Northern Ohio and South Central Michigan.**

### *5A) 16:05:57 EDT: Sammis-Star 345-kV line tripped by protective zone 3 relay.*

A fault did not cause a relay to operate and remove the Sammis-Star 345-kV line from service: high current flow above the emergency rating of the line coupled with depressed voltage due to the overload appeared to relay as a remote fault. As a result of the blockage, more power flowed into Northern Ohio from northwest-central Ohio, southeast Michigan and Ontario. Figure 7 shows the blockage and a graph of the power flow redistribution into Northern Ohio.

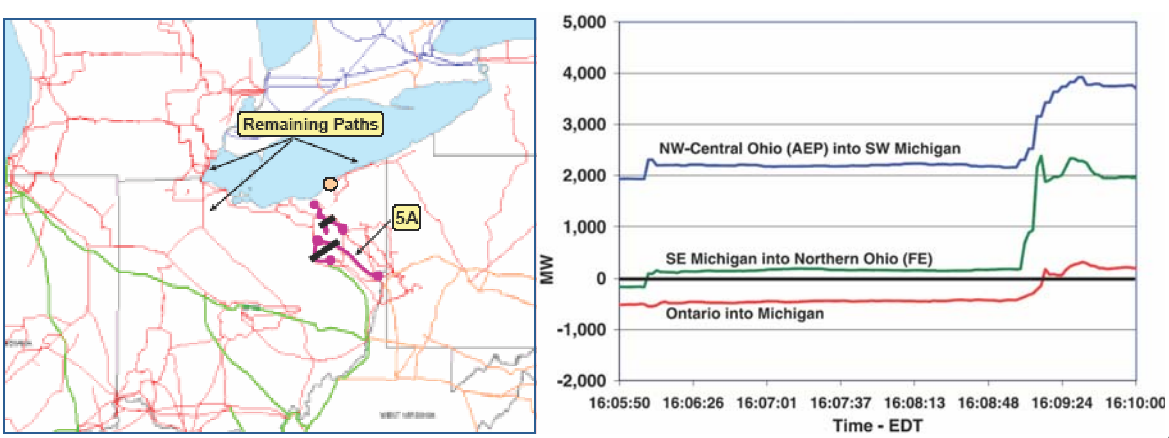


**Figure 6. Sammis-Star 345-kV line fault (left). Redistribution of power flows into Northern Ohio (right).**[16]

[16] U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada," p. 77, 78: April 2004.

*5B) 16:08:59 EDT: Galion-Ohio Central-Muskingum 345-kV line tripped.*

The Galion-Ohio Central-Muskingum line tripped three times on a ground fault: first at Muskingum, then at Ohio Central and finally at Galion.

*5C) 16:09:06 EDT: East Lima-Fostoria Central 345-kV line tripped, causing a large power swing from Pennsylvania and New York through Ontario to Michigan.*

After the Galion–Ohio Central–Muskingum and numerous other lines tripped in central Ohio, the East Lima – Fostoria Central 345-kV line tripped on a zone 3 relay operation, not due to a fault, but due high current and low voltage.

The above two events blocked power flow paths into Northern Ohio from the south. Figure 7 shows the beginning of the electrical isolation that Northern Ohio experienced during the early stage of the cascade and the increased power flow into from New York and Ontario to make up for the shortfall.

The power flow from Ontario into Northern Ohio increased dramatically as it was becoming more and more isolated. As a result of the increased power demand from Ontario the power flow into New York from PJM also increased.

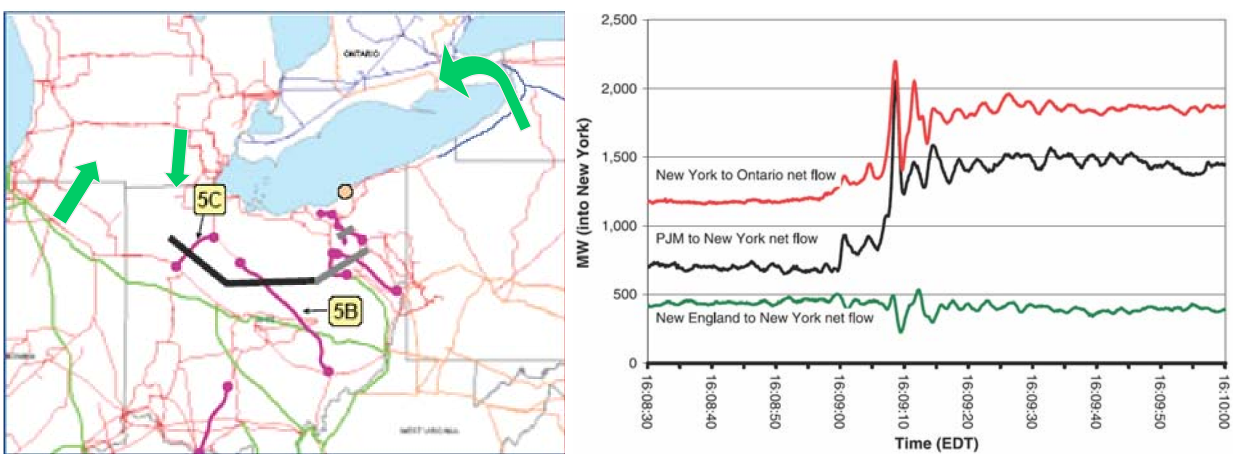


**Figure 7. Redistribution of power flow into northern Ohio after the East Lima – Fostoria 345-kV line tripped.**[17]

[17] U.S.-Canada Power System Outage Task Force. “Final Report on the August 14, 2003 Blackout in the United States and Canada,” p. 79, 80: April 2004.

***5D) 16:09:08 EDT to 16:10:27 EDT: Multiple power plants tripped, 946 MW of power brought offline.***

Michigan Cogeneration Venture (300 MW), Avon Lake 7 unit (82 MW), Burger units 3, 4, and 5 (355 MW), and Kinder Morgan units 3, 6, 7 (209 MW) tripped for a total of 946 MW of power being taken offline in the Midwest. These generating units were taken offline due to under voltage conditions. As a result, voltages dropped further due to the imbalance between high loads and limited transmission and generation capability.

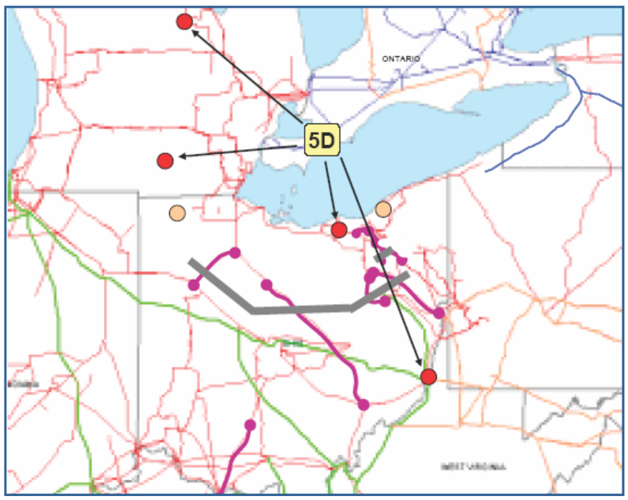


**Figure 8. Multiple power plants in Ohio and Michigan tripped.**[18]

## *Phase 6: The full cascade.*

The timeline of the full cascade is broken down into three sections and the firsts is summarized in the following timeline:

***6A) 16:10:36 EDT to 16:10:39 EDT: Transmission lines disconnected across Michigan and Northern Ohio, generation shut down in central Michigan and northern Ohio, and northern Ohio separated from Pennsylvania.***

Figure 9 shows the timeline of the early stages of the separation of Michigan into east-west.

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[18] U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada," p. 82: April 2004.

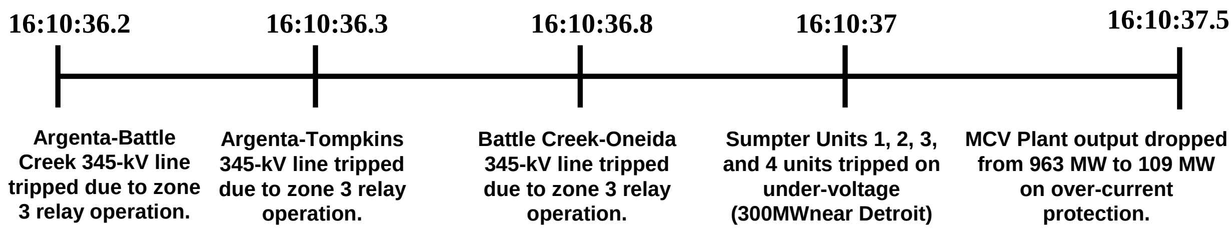


**Figure 9. Timeline of transmission and generation loss in Michigan and northern Ohio.**

The above line outages interrupted the east to west transmission paths into Detroit from south and south central Michigan. The lines tripped on zone 3 relay operations due to depressed voltages and heavy loading rather than a fault. The Sumpter units, in response to the lines outages, tripped on under voltage conditions. The left side of Figure 10 shows the conditions that led up to the separation of Michigan into east and west.

### *6B) and 6C) 16:10:37 EDT to 16:10:38.6 EDT: Western and Eastern Michigan separation (6B) and separation of Ohio from Pennsylvania (6C).*

The following timeline shows the complete separation of Michigan into east and west and the separation of Ohio and Pennsylvania.

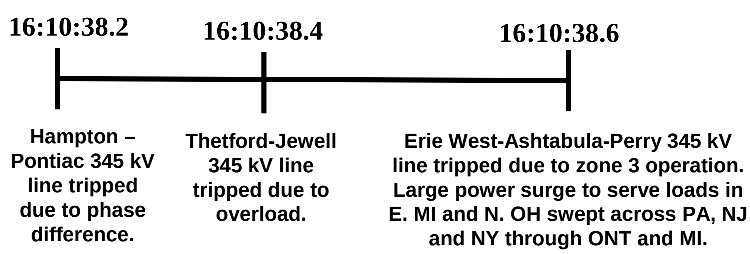


**Figure 10. Timeline of the separation of Michigan into east and west and the Ohio from Pennsylvania.**

After the Argenta lines tripped, the phase angle between eastern and western Michigan began to differ by an increasing amount and the Hampton-Pontiac line and Thetford-Jewell finally tripped out of service completing the separation of Michigan into east and west. This increased the power demand in the Cleveland area from Pennsylvania which caused power surges in the Erie West–Ashtabula–Perry 345-kV line and the line tripped due to a zone 3 relay operation due to high currents and low voltage completing the separation of Ohio and Pennsylvania (Figure 11).

The only remaining path for power to flow into northern Ohio and southeast Michigan was through Ontario. This caused power to surge from New York into Ontario.

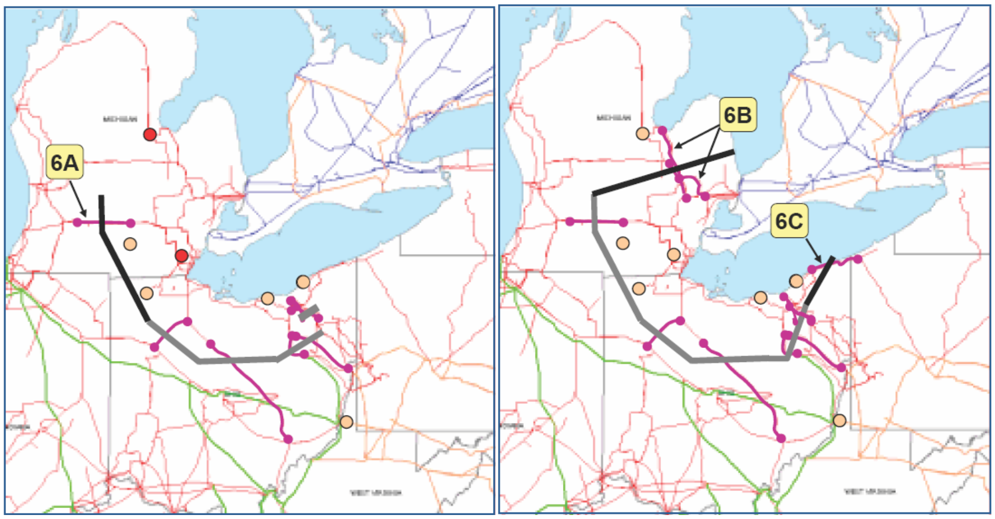


**Figure 11. Transmission and generation trips in Michigan (left). East-west separation in Michigan and Ohio separation from Pennsylvania (right).[19]**

***6D) 16:10:39 EDT to 16:10:46 EDT: More transmission lines and power plants fail in northern Ohio and eastern Michigan.***

With voltage levels low and currents high through the remaining lines, a number of lines in northern Ohio and eastern Michigan tripped causing Toledo and Cleveland to be electrically separated from each other and Detroit. Internal generation was already reduced in the islands that were just formed due to the outage of some power plants earlier on. Demand for power was outstripping supply and frequency was falling. More power plants went offline. Figure 11 shows the islanding of Cleveland and Toledo and the power flows on one transmission line from Ontario to Michigan.

[19] U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada," p. 83, 85: April 2004.

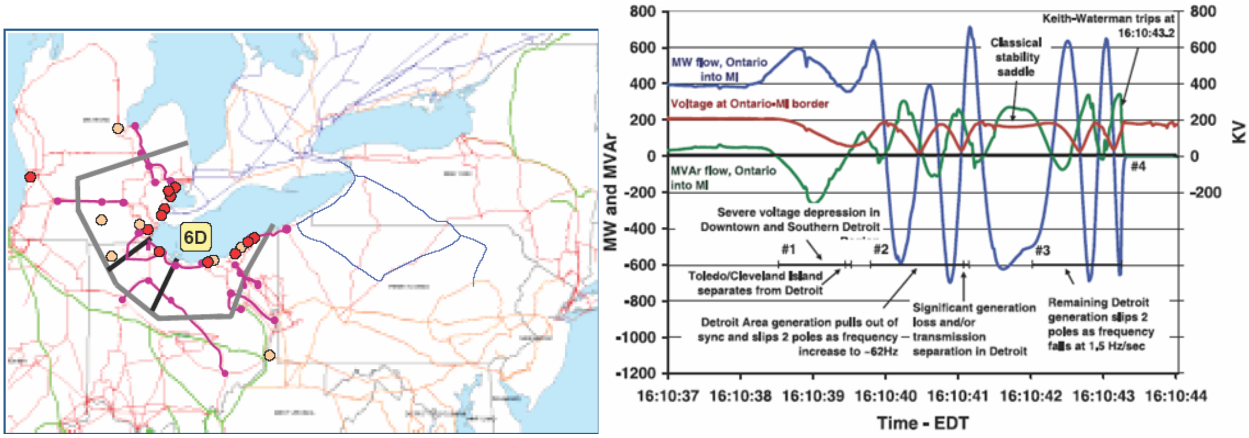


**Figure 12. Islanding of Toledo and Cleveland (left). Power flows across the Keith-Waterman line (one of the lines connecting Michigan to Ontario lines (right).[20]**

The right side of Figure 11 shows that the power flow into Michigan from Ontario increased at approximately 16:10:38.6 which corresponds to the Erie West–Ashtabula–Perry 345-kV line failure. At this time, the reactive power supplied by Ontario decreased as well which caused the voltage to decrease significantly.  Since Michigan was suddenly no longer supplying power to northern Ohio, there was now too much power flowing into Michigan as evidenced by the oscillations in real and reactive power and voltage.  Power flow reversed across the Ontario Michigan border and the sudden swings cause more line and power plant outages which cause severe dynamic instability and eventually the collapse of the Keith-Waterman line.

***6E), 6F) and 6G) 16:10:39 EDT to 16:10:45 EDT: Western Pennsylvania separated from New York (6E and 6F) and isolation of the northeast portion of the Eastern Interconnection (6G).***

The following timeline shows the complete isolation of the northeast portion of the Eastern Interconnection.

[20] U.S.-Canada Power System Outage Task Force. "Final Report on the August 14, 2003 Blackout in the United States and Canada," p. 88, 88: April 2004.

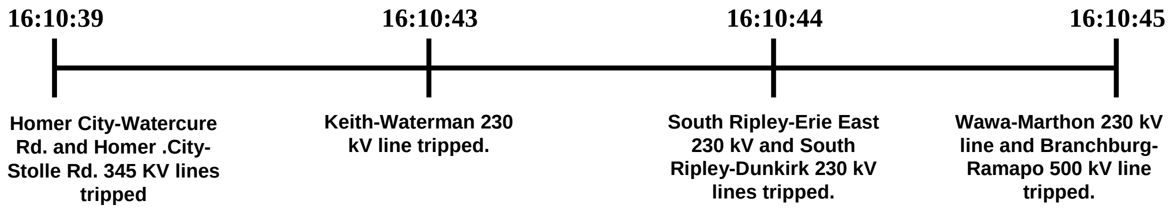


**Figure 13.Time line of the separation of western Pennsylvania from New York (left) and New Jersey and northern Ontario from the northeast portion of the Eastern Interconnection.**

The severe power swings out of Michigan into Ontario and New York caused both lines out of Homer City to trip on zone 1 relays separating Pennsylvania from New York. These are relatively long high impedance lines which make them more susceptible to tripping on power swings.

As stated earlier, the Keith-Waterman 230-kV line tripped out due to due apparent impedance (high current swings and low voltage). The remaining line from Ontario into Michigan (Wawa-Marathon) experienced a power surge and oscillations after the Keith-Waterman line went offline.

The only line remaining connecting New York to Ontario soon tripped due to an overload completing the cascade and separating the Midwest and Ontario from the rest of the Eastern Interconnection. Figure 14 shows the islands that were formed at the completion of the cascade.

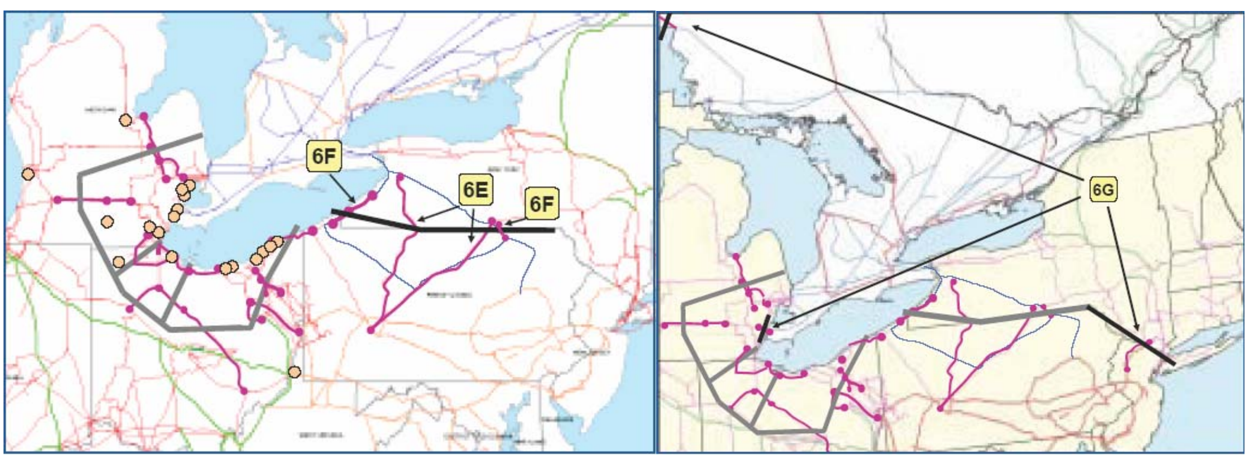


**Figure 14. Separation of western Pennsylvania from the New York and the rest of the Midwest and Ontario from the Eastern Interconnection.[21]**

[21] U.S.-Canada Power System Outage Task Force. “Final Report on the August 14, 2003 Blackout in the United States and Canada,” p. 89, 89: April 2004.

### *Phase 7: The forming of electrical islands.*

The 6$^{th}$ phase of the cascade was about dynamic system oscillations, the last phase deals with finding an internal balance between loads and generation. With the generating capacity already reduced in the each of the islands due to power plants being taken off line, there was either not enough generating capacity to balance the load or the dynamic instability caused by the power surges in turn cause the more transmission lines and generators to trip. As a result, most islands blacked out.

# Chapter 5: Recommendations

The large scale blackout on August 14, 2003 was avoidable. The direct causes and contributing factors include: 1) Failure to maintain adequate reactive power support, 2) Failure to ensure operation within secure limits, 3) Inadequate vegetation management, 4) Inadequate operator training, 5) Failure to identify emergency conditions and communicate the status to neighboring regions and 6) inadequate regional-scale visibility over the bulk power systems.

In addition, the August 2003 blackout had the following in common with seven other major U.S. blackouts: 1) conductor contact with trees, 2) dynamic reactive output of generators, 3) system visibility procedures and operator tools, 4) system operation within safe limits, 5) coordination of system protection (transmission and generation), 6) effectiveness of communication, 7) need for safety nets, and 8) training of operating personnel.

Many of the causes and contributing factors of the August 2003 blackout were also causes or contributing factors of the previous seven major U.S. blackouts. As a result, the recommendations given by the report prepared by the U.S.-Canada Power System Outage Task Force, *August 14th Blackout: Causes and Recommendations*, reinforce the recommendations made after each of the seven other major U.S. blackouts and address the causes and contributing factors of the August 2003 blackout. The list of recommendations made by the U.S.-Canada Power System Outage Task Force is presented in Appendix I. For a complete description, refer to the aforementioned report.

# Appendix 1: Overview of Task Force Recommendations: Titles Only

## *Group I. Institutional Issues Related to Reliability*

1. Make reliability standards mandatory and enforceable, with penalties for noncompliance.
2. Develop a regulator-approved funding mechanism for NERC and the regional reliability councils, to ensure their independence from the parties they oversee.
3. Strengthen the institutional framework for reliability management in North America.
4. Clarify that prudent expenditures and investments for bulk system reliability (including investments in new technologies) will be recoverable through transmission rates.
5. Track implementation of recommended actions to improve reliability.
6. FERC should not approve the operation of new RTOs or ISOs until they have met minimum functional requirements.
7. Require any entity operating as part of the bulk power system to be a member of a regional reliability council if it operates within the council's footprint.
8. Shield operators who initiate load shedding pursuant to approved guidelines from liability or retaliation.
9. Integrate a "reliability impact" consideration into the regulatory decision-making process.
10. Establish an independent source of reliability performance information.
11. Establish requirements for collection and reporting of data needed for post-blackout analyses.
12. Commission an independent study of the relationships among industry restructuring, competition, and reliability.
13. DOE should expand its research programs on reliability-related tools and technologies.
14. Establish a standing framework for the conduct of future blackout and disturbance investigations.

## *Group II. Support and Strengthen NERC's Actions of February 10, 2004*

15. Correct the direct causes of the August 14, 2003 blackout.
16. Establish enforceable standards for maintenance of electrical clearances in right-of-way areas.
17. Strengthen the NERC Compliance Enforcement Program.
18. Support and strengthen NERC's Reliability Readiness Audit Program.
19. Improve near-term and long-term training and certification requirements for operators, reliability coordinators, and operator support staff.
20. Establish clear definitions for normal, alert and emergency operational system conditions. Clarify roles, responsibilities, and authorities of reliability coordinators and control areas under each condition.
21. Make more effective and wider use of system protection measures.
22. Evaluate and adopt better real-time tools for operators and reliability coordinators.
23. Strengthen reactive power and voltage control practices in all NERC regions.
24. Improve quality of system modeling data and data exchange practices.
25. NERC should reevaluate its existing reliability standards development process and accelerate the adoption of enforceable standards.
26. Tighten communications protocols, especially for communications during alerts and emergencies. Upgrade communication system hardware where appropriate.
27. Develop enforceable standards for transmission line ratings.

28. Require use of time-synchronized data recorders.
29. Evaluate and disseminate lessons learned during system restoration.
30. Clarify criteria for identification of operationally critical facilities, and improve dissemination of updated information on unplanned outages.
31. Clarify that the transmission loading relief (TLR) process should not be used in situations involving an actual violation of an Operating Security Limit. Streamline the TLR process.

## *Group III. Physical and Cyber Security of North American Bulk Power Systems*

32. Implement NERC IT standards.
33. Develop and deploy IT management procedures.
34. Develop corporate-level IT security governance and strategies.
35. Implement controls to manage system health, network monitoring, and incident management.
36. Initiate U.S.-Canada risk management study.
37. Improve IT forensic and diagnostic capabilities.
38. Assess IT risk and vulnerability at scheduled intervals.
39. Develop capability to detect wireless and remote wire line intrusion and surveillance.
40. Control access to operationally sensitive equipment.
41. NERC should provide guidance on employee background checks.
42. Confirm NERC ES-ISAC as the central point for sharing security information and analysis.
43. Establish clear authority for physical and cyber security.
44. Develop procedures to prevent or mitigate inappropriate disclosure of information.

## *Group IV. Canadian Nuclear Power Sector*

45. The Task Force recommends that the Canadian Nuclear Safety Commission request Ontario Power Generation and Bruce Power to review operating procedures and operator training associated with the use of adjuster rods.
46. The Task Force recommends that the Canadian Nuclear Safety Commission purchase and install backup generation equipment.

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