NERC

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

AEP Summer 2022 Storm Event Observations

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RELIABILITY | RESILIENCE | SECURITY

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Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of NERC and the six Regional Entities, is a highly reliable, resilient, and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security
Because nearly 400 million citizens in North America are counting on us

The North American BPS is made up of six Regional Entities as shown on the map and in the corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one Regional Entity while associated Transmission Owners/Operators participate in another.

MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

Executive Summary

This report provides an overview of the National Weather Service declared derecho storm that went through the Columbus, Ohio area on June 13-14, 2022, and the subsequent load shedding events on June 14-15, 2022. Immediately following the storm, there were record and near record high temperatures in Columbus and Eastern Ohio. The record high temperatures increased the power demand in the Columbus area to levels above normal.

In the American Electric Power (AEP) area, the derecho storm displaced vegetation and caused outages of many 69 kV transmission lines and substations, numerous 138 kV lines and substations, and one 345 kV transmissions line. Due to the forced transmission outages around the Columbus area and higher demand because of the hot and humid conditions following the storm, AEP experienced heavier than normal load on the remaining local transmission facilities. Where possible, AEP and PJM utilized transmission system reconfiguration and re-dispatch of generation to reduce actual overloads and contingent overloads. Ultimately, to alleviate system issues, PJM implemented 100 MW of demand response (non-firm load), 500 MW of firm AEP load in the Columbus metro area on June 14, and 450 MW of firm load on June 15.

This report identifies two observations involving this event. The first one is the close coordination of activities between AEP and PJM along with a recommendation to conduct a joint after action review.

The second observation involves post storm activities relating to vegetation displacement. This observation has four related post storm recommendations that would help reduce vegetation impact.

Introduction

BPS reliability includes preventing, reducing, and eliminating overloads, preserving the overall system integrity, minimizing system and/or facility downtime, and efficient system restoration. Constant monitoring and management of actual and contingent system loading maintains the overall reliability of the BPS. There are two primary reasons for the performance of load shedding on the BPS. The first reason is lack of generation required to maintain balance with system load. The second reason is a problem with the transmission path(s) between two points. Load shedding is a designed-in system-operating tool for the BPS that is used when all other operating measures have failed to mitigate the situation. Some other operating measures include the following:

- **System Reconfiguration (Switching):** Transmission lines or substation breakers may be opened to force power flow in a certain direction. This would be similar to shutting down a road and forcing traffic to go in a specified way. In this case, the storm broke many of the transmission paths into the Columbus area, thus limiting the ability to reconfigure the system.
- **Generation Re-dispatch:** The costs associated with running generating units principally determines the order of how generation is scheduled. The least expensive units are the first units dispatched. There are many occasions when reliability reasons (generation re-dispatch) dictate the dispatch of a particular (non-economic) generator. It is important to note that generation re-dispatch requires the availability of transmission paths from the generator to the load. In this case, the storms from the previous evening adversely affected the transmission paths and limited the impact of generation re-dispatch.

In the case of the aforementioned primary reasons, protecting the integrity of the entire transmission system occasionally requires load shedding. In some instances, elements may experience an actual overload condition. After exhausting switching and generation re-dispatch options, the only way to relieve the overload condition is to load shed.

In other cases, “contingency analysis” identifies a severe cascading event that can only be resolved by load shedding. When describing contingencies, the term “N-1” is used. The term “N-1” refers to the next event that may happen. For the BPS, the “N-1” contingency is described as “on the loss of Item X (where X is either a generator or a transmission path), item Y (another transmission path) will be above a specified emergency rating.” If Item Y remains above its emergency rating, it runs the risk of failure. Constant monitoring and managing of actual and contingent loading maintains the overall reliability of the BPS.

Advanced computer systems perform contingency analysis and provide the results to NERC-certified system operators for review. The computer system performs a simulation that removes each line from service and ranks the severity of each contingency. Depending on the severity of the contingent violated limit, the operator will either continue to monitor, direct system reconfiguration, generation re-dispatch, or shed load.

When the advanced computer system performs the contingency analysis, it also performs a cascade contingency analysis; the cascade analysis is performed up to five times (“N-5”). If removing line A from service (N-1) causes any line (B) to be 115% above its highest emergency rating, the cascade analysis sub-process starts. If line B is removed from service (N-2), and that removal causes any line (C) to be 115% above its highest emergency rating, the cascade analysis is repeated three more times (total of five). If lines remain overloaded after the removal of five lines (“N-5’’), and no other alternative exists, then load is shed on a “pre-contingent” basis to alleviate the identified potential cascade scenario. The pre-contingency load shed is performed to prevent the first contingency (removal of line A), in the cascade sequence of five, from occurring. PJM performs up to an N-5 analysis on facilities over 115% of the facility’s highest emergency rating. This feature was added to the PJM Energy Management System (EMS) in 2015. The addition of this analysis to the EMS was in response to industry lessons learned on cascading analysis from the

Southwest blackout.[1] AEP also performed similar cascade studies during the event to independently validate the cascade analysis performed by PJM.

It is important to note that operators may need to perform load shedding to mitigate actual overloads and to prevent potential cascading[2] of multiple overloaded system elements.

This document describes an actual incident that developed because of severe weather traversing the upper Midwest in the summer of 2022. This event unfolded over the period of June 13-15, resulted in decisions to shed load on several occasions. Those occasions included both actual overloads and pre-contingent cascade analysis events. Analysis of this event resulted in multiple observations with corresponding recommendations for improvement shared in detail in **Chapter 6:**.

Event Overview

A severe storm system that was declared a derecho[3] by the National Weather Service moved through Michigan, Indiana, and Ohio late Monday, June 13, 2022 and early Tuesday, June 14. The storm brought strong straight-line winds (80-90+ mph) and three tornadoes (maximum winds of 105 mph) and produced a swath of continuous wind damage from Northeast Indiana and Northwest Ohio through sections of Northcentral and Northeast Ohio. Additionally, a large macroburst tracked across Wayne and Holmes Counties in AEP Ohio's Canton district with estimated winds 80-90+ mph. The city of Columbus and its surrounding suburbs were on the very southern edge of the derecho, and derecho-type wind gusts (swaths of 60-75+ mph) occurred mainly north and east of the Columbus area.

Record and near record high temperatures in Columbus and Eastern Ohio on Tuesday, June 14, and Wednesday, June 15, immediately followed the derecho storm. The record high temperatures increased the power demand in the Columbus area to levels above normal.

This storm system caused the assets described in **Table I.1** to go out of service throughout the AEP zone in the PJM footprint.

Table I.1: Transmission Facilities Out of Service as of 9:00 a.m. June 14

Transmission Lines	Transmission Substations
69 kV lines (26)	69 kV substations (31)
138 kV lines (15)	138 kV substations (13)
345 kV line (1)	

[1] September 2011 Southwest Blackout Report https://www.nerc.com/pa/rrm/ea/Pages/September-2011-Southwest-Blackout-Event.aspx

[2] The NERC Glossary of Terms (Glossary_of_Terms.pdf (nerc.com)) defines Cascading as The uncontrolled successive loss of System Elements triggered by an incident at any location. Cascading results in widespread electric service interruption that cannot be restrained from sequentially spreading beyond an area predetermined by studies.

[3] The National Weather Service defines a derecho as a widespread, long-lived wind storm that is associated with a band of rapidly moving showers or thunderstorms. Although a derecho can produce destruction similar to the strength of tornadoes, the damage typically is directed in one direction along a relatively straight swath. As a result, the term "straight-line wind damage" sometimes is used to describe derecho damage. By definition, if the wind damage swath extends more than 240 miles (about 400 kilometers) and includes wind gusts of at least 58 mph (93 km/h) or greater along most of its length, then the event may be classified as a derecho.

In the AEP area, the storm displaced vegetation and caused outages of many 69 kV transmission lines and substations, numerous 138 kV lines and substations, and one 345 kV transmissions line. Due to the forced transmission outages around the Columbus area and higher demand because of the hot and humid conditions following the storm, AEP experienced heavier than normal loading of the remaining local transmission facilities. Where possible, AEP and PJM utilized transmission system reconfiguration and re-dispatch of generation in an attempt to reduce these actual overloads and contingent overloads. Ultimately, PJM implemented 100 MW of demand response (non-firm load) and PJM directed the reduction of 500 MWs of firm AEP load in the Columbus metro area on June 14, 2022, and 450 MWs of firm load on June 15, 2022, to alleviate system issues.

Chapter 1: Pre-Storm Conditions and Preparation

PJM, as the Reliability Coordinator (RC), analyzed upcoming hot weather and declared a hot weather alert for operating days June 14 and June 15. A hot weather alert notified PJM entities and PJM neighbors of upcoming conditions that could affect the Bulk Electric System (BES) in the PJM footprint. As a result of this alert, AEP recalled 22 scheduled transmission outages to help maintain BES strength and reliability for possible issues that could arise with the forecasted extreme heat. This strengthened PJM/AEP's ability to handle the heat and anticipated heavy load conditions.

Chapter 2: Storm and Its Impacts

The National Weather Service reported that a line of severe thunderstorms moved rapidly southeast out of Michigan and Indiana late in the evening hours of Monday, June 13, 2022, (see **Figure 2.1**). During the pre-dawn hours of Tuesday, June 14, the National Weather Service tracked a warm front that separated very hot and humid conditions to the southwest from cooler and drier conditions to the northeast. This storm was anticipated to affect the electric distribution system as it had in several other areas it had passed through, but it gained momentum as it tracked into the AEP electric transmission zone.

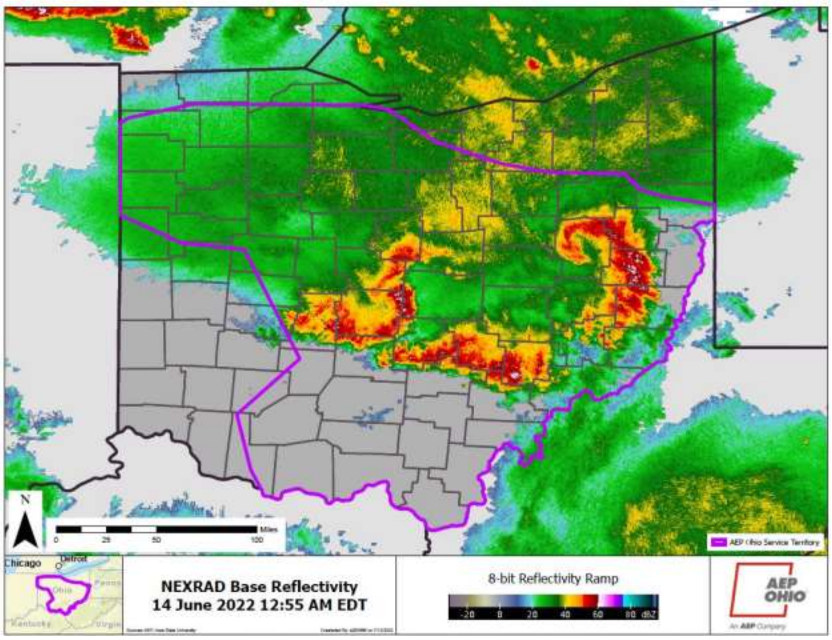

Figure 2.1: Radar Map of Severe Thunderstorms on June 13, 2022

Severe thunderstorms produced a derecho with winds estimated at 60-70 mph from Northwest Ohio through interior sections of Northcentral and Northeast Ohio. A swath from Richland, Ashland, and Morrow Counties through Wayne, Holmes, and Knox Counties was particularly hard hit with widespread tree damage from winds likely around 80 mph. A large macroburst that tracked across Wayne and Holmes counties produced estimated 80-90+ mph winds from Wooster Township through Millersburg. Thousands of trees were knocked down along this path, many of which fell on homes, vehicles, and power lines, causing widespread power outages. Clean-up and power restoration in Richland, Ashland, Morrow, Wayne, Holmes, and Knox counties took several days. In addition to the straight-line winds, three EF-1 tornadoes touched down. The first tornado touched down five miles northeast of Mt. Gilead, ended six miles northwest of Chesterville, and had maximum winds of 97 mph. The second tornado touched down in Chesterville and ended five miles southwest of Fredericktown; it had maximum winds of 105 mph. The third tornado touched down three miles north of Butler and ended four miles south of Perrysville. These tornadoes also damaged or destroyed several barns and outbuildings.

Chapter 3: Storm Restoration and Hot Weather Alert Response

At 9:00 a.m. on June 14, 2022, AEP had 69 kV lines (26), 138 kV lines (15), and a 345 kV line (1) out of service as a result of these storms. For the Columbus area, outaged lines included one 69 kV line and two 138 kV lines. AEP Transmission Control Center employees were busy performing restoration activities, daily operations, and managing a PJM Hot Weather Alert.

The load on many of the facilities around the Columbus area was higher than typical because three lines that normally served the Columbus area had tripped during the derecho storm, the near record temperatures, and the higher loading on June 14. In the early afternoon, several 138 kV facilities tripped within a short period of time, resulting in actual loading on other facilities exceeding the highest emergency rating of the facility. PJM issued load shed directives on actual thermal overloads following the outages that occurred. After resolving actual thermal overloads, PJM and AEP worked together to evaluate N-5 cascade analysis violations. PJM called an energy emergency alert (EEA) for impacted areas, re-dispatched available generation to reduce impacts to effected areas, and reconfigured the transmission system when possible. When those remedies were insufficient, load was directed to be shed in several zones around the Columbus area due to the outages in order to maintain reliability of the BES in the AEP Columbus area.

The pre-contingency load shed directive for the N-5 cascade analysis was based off the system loading and system configuration at the time. Load shed, based on the N-5 cascade study, was directed in the amount to reduce and maintain the post-contingency flow below 115% of the facility's highest emergency rating. PJM's policy is to determine a power flow limit that the Transmission Owner needs to stay below rather than request a specific amount of load shed. After AEP completed their directed load shed, all potential cascading outages were alleviated. AEP continued to work on the restoration of out of service facilities; four transmission lines were restored on operating day June 14.

PJM was in close coordination with AEP to restore load as system conditions changed. As the day progressed into evening, the overall system load decreased, transmission lines returned to service, and load that was shed was restored. PJM and AEP operators conducted studies in parallel to validate that the system would not enter back into N-5 conditions. After system conditions allowed, load was gradually restored until all shed loads were restored the night of June 14.

Chapter 4: Restoration Mode

On the start of June 15, 2022, AEP was still in restoration mode for lines in the AEP zone outside the Columbus area and in right-of-way clearing mode for lines inside the Columbus area. Early in the operating day, four transmission lines tripped in the Columbus area. PJM directed AEP to shed load in the Columbus area to maintain BES reliability. As loading increased with the hot weather, the AEP system operator proactively shed load due to recognizing similar conditions from operating day June 14.

Along with the actions that AEP proactively took, AEP and PJM were in constant communication and closely collaborating. AEP and PJM continued to reconfigure the transmission system where possible and re-dispatch available generation in the area. PJM also used EEA procedures to call on interruptible load(s) in the Columbus area. PJM and AEP worked together to evaluate N-5 cascade analysis violations. Similar to June 14, load was directed to be shed in several zones around the Columbus area due to the outages in order to maintain reliability of the BES.

AEP continued to work on the restoration of out-of-service facilities and restored nine transmission lines on the operating day of June 15. During the evening as overall system load decreased and transmission lines returned to service, load that was shed was restored. PJM and AEP operators ran studies in parallel to validate that the system would not enter back into N-5 conditions. Load was restored in incremental amounts to maintain post-contingency flows under the facility's highest emergency rating. When system conditions allowed, all load that was shed was restored the night of June 15.

Although temperatures on the operating day of June 16 fell to a more manageable point, and AEP was still in restoration mode and monitoring system conditions. AEP, while not fully in the clear, did not have to shed load on the operating day of June 16. During this operating day, two outages occurred that resulted in AEP and PJM continuing to reconfigure the transmission system and re-dispatching available generation in the area. PJM also used EEA procedures to call on interruptible load(s) in the Columbus area. AEP continued to work on the restoration of out of service facilities and restored six transmission lines on the operating of day June 16.

Chapter 5: Overall Analysis of Event

PJM issued a hot weather alert for June 14 and AEP cancelled 22 transmission outages prior to the June 14 operating day. There were three transmission elements, a bus, and two transmission lines (138 kV and a 345 kV line) that were not put back into service. A 345 kV line was put back into service during the event restoration, making the 345 kV system more reliable.

AEP experienced hot weather on June 12 and June 13 and did not identify any vegetation issues. The loads for June 13-16 were consistent with the expected heat wave. After the storm that went through the AEP zone, vegetation was displaced, causing vegetation contact to occur across the Columbus area. On June 14, distance-to-fault information from relays was used to identify fault locations. Crews removed vegetation and put lines back into service. Line inspection/patrols were focused on the locations that experienced the initial faults. On June 15, as load increased because of actual high temperatures, some of the lines that were put back into service on June 14 subsequently tripped due to previously undetected vegetation issues. These line sections were again identified with distance-to-fault information, and crews conducted trimming and put lines back into service. AEP system load levels shown in **Table 5.1** indicate that the load increases were not out of the ordinary.

Table 5.1: PJM AEP Zone Daily Peak Load and Load Shed in megawatts (MW)

	6/12/22	6/13/22	6/14/22	6/15/22	6/16/22
Daily Peak	16,643	21,432	20,283	21, 239	21, 411
Load Shed	0	0	500	450	

The actions displayed by PJM and AEP during this event directly reflect the operator's ability to apply their annual training. AEP operators were tasked with deciphering data, coordinating with PJM, taking phones calls, and writing switching orders all while maintaining reliability of the AEP zone of the PJM transmission system. AEP and PJM operators were also tasked with maintaining public safety during this event. During this event, AEP called in extra operators to assist with all the tasks that were relevant to restoration, reliability, and safety. AEP continually reviews communication protocols to ensure broad awareness of service restoration efforts.

Transmission System configuration and generation re-dispatch were the first tools used to help to alleviate issues. At the time when there were no more reconfigurations or re-dispatching that could be completed, load shed was required to maintain reliability of the Columbus area BES. AEP system operators with the assistance of PJM identified areas where load shed was required. The load that AEP shed was directly correlated to parts of the Columbus area where overloads were directly experienced. As a result of the load shed, system constraints were alleviated, and the BES remained reliable. The load shed was not able to be rotated during the event due to the location of the constraints on the Columbus area system; AEP utilized their internal load shed tools to the extent that the operators could. While some of the contingencies were not previously identified during the operating day, a study was completed when time was available, and the load shed amount was identified.

During the load shed, the collaboration between PJM, AEP Transmission Control Center employees, and AEP Distribution Control Center employees showed the ability to work together between teams and maintain reliability of the BES. AEP and PJM staff were continuously talking, verifying what each was seeing, and verifying ratings and system configuration prior to making any system changes. During this time, there were no discrepancies between AEP or PJM system operating limits and the ratings supplied by AEP transmission planning. AEP and PJM normal system coordination and system updates were completed and verified as required. During the event, a continuous peer check occurred to make sure both PJM and AEP understood any actions to be taken. AEP was also continuously running system studies, such as state estimator, real-time contingency analysis, and engineering studies that allowed AEP staff to coordinate with PJM more easily. PJM (as the RC) and AEP (as the Transmission Operator) worked through this event while maintaining reliability.

PJM worked closely with AEP to develop the load shed plan. Load was shed in the areas that had the highest calculated ability to relieve the N-5 conditions. AEP was reporting to PJM how much available load could be shed at each station. The objective was to shed the least amount of load possible to relieve the condition while respecting and minimizing any impact on critical load. Typically, load that is the closest to the overload or violation has the highest impact. The further away from the overload, the less impact the load has on the violation. The load shed was very targeted as the objective was to shed the least amount of load possible while still alleviating all potential cascading outages.

Chapter 6: Observations and Recommendations

Although not meeting the categorized event criteria in the ERO Event Analysis Process, analysis of this system event resulted in multiple observations that highlighted opportunities for improvement and potential corrective actions. Circumstances and conditions leading up to the operating environment during this event are likely to occur anywhere on the grid. Industry must learn from the experiences of their partners on the grid and implement resulting recommendations and corrective actions like those offered in the following.

- **Observation**
  Throughout this event, PJM and AEP operators relied on their training and kept in constant communication to navigate through this challenging multi-day situation. This cooperative effort allowed them to efficiently identify real-time and contingent overloads and develop effective operating plans to minimize the negative impact of the circumstances threatening the stability of the transmission system in real-time. The containment of the problem and stabilization of the system resulted from shared problem-solving and operating activities that must be reviewed to cultivate areas for continuous improvement opportunities.
  - **Recommendation**
    AEP and PJM should conduct a joint after action review to identify opportunities to reinforce and strengthen what went right, and to identify any opportunities for improvement in how they communicate and collaborate.
- **Observation**
  As a result of the storm that went through the AEP zone, vegetation was displaced, causing vegetation contact to occur across the Columbus area.
  - **Recommendations**
    - Entities experiencing high wind events should patrol their lines to mitigate potential post-storm vegetation issues. This includes identifying ground cover that might have been displaced into the tree tops that could result in vegetation encroaching into transmission lines.
    - Entities that could experience high winds events should patrol their lines to identify potential hazards, such as ground cover that could be blown into lines and mitigate those potential hazards as part of a routine vegetation management program
    - During restoration, vegetation management crews should photographically document the issues they are encountering. This will help inform their vegetation management process of improvement opportunities and how different storm characteristics can affect vegetation and clearances (from transmission lines).
    - When time permits (post storm), use of LIDAR could help establish temporary limits when encroachments are changed due to displaced vegetation. This would help crews identify which lines to work on and return to original facility ratings. The temporary limits would assist the operators with better monitoring and control of the overall transmission system.

Appendix A: Team Members

Team Members	
ReliabilityFirst – Event Lead	
Dwayne Fewless	Principal Analyst, Operational Analysis and Awareness (lead)
Bill Crossland	Principal Engineer, Protection
AEP	
Aubrey Patterson	EDOps O&P Compliance Supv (lead)
David Ball	VP Energy Delivery Ops
Summer Moses	Dir Energy Delivery Ops Support
Dennis Sauriol	Dir Trans RealTime Reliability
David Browning	Dir Energy Delivery System Ops
Julie Kennedy	Dir Emerg Prep & Resiliency
Chris Shaffer	Trans Oprs Reliability Mgr
Ryan Cox	Trans Opers Reliability Supv
Roz McAuley	Eng Del System Ops Mgr
LeGrand Whitlow	Protection & Control Supv
Jason Mulligan	Engineer
Kevin Patton	Dir Vegetation Mgmt
Eddie D Hannah JR.	TFS T-Line Tech Svcs Mgr
PJM	
Chris Moran	Senior Lead Compliance Analyst, NERC Compliance (lead)
Matthew Wharton	Senior Lead Reliability Engineer, Reliability Engineering
Jennifer Willigers	Compliance Analyst, Operational Excellence
Paul McGlynn	Executive Director System Operations
Donnie Bielak	Senior Manager Dispatch
Kevin Hatch	Manager Reliability Engineering
NERC	
Valerie Carter-Ridley	Lead Engineer - Event Analysis (lead)
Ed Ruck	Senior Engineer - Event Analysis
FERC	
Tarek Aly	Electrical Engineer, Office of Electric Reliability (OER)