ORNL/TM-2024/3283

Winter Storm Elliott: Energy Emergency Alert Lessons Learned

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February 2024

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ORNL/TM-2024/3283

National Security Emerging Technologies Division

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Prepared by
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managed by
UT-BATTELLE LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ABBREVIATIONS

CAISO	California Independent System Operator
EEA	Energy Emergency Alert
ELCP	Emergency Load Curtailment Program
GRIDS	Grid Reliability Initiative Utilizing Data Standardization
KUB	Knoxville Utilities Board
LPC	local power company
MISO	Midcontinent Independent System Operator
MLGW	Memphis Light, Gas and Water
NCPA	Northern California Power Agency
NERC	North American Electric Reliability Corporation
NES	Nashville Electric Service
PSA	public service announcement
RCIS	Reliability Coordinators Information System
RTO	regional transmission organization
SCADA	Supervisory control and data acquisition
TVA	Tennessee Valley Authority

1. INTRODUCTION

Power blackouts in the United States in 2022 highlighted the need for better communication and planning among power grid stakeholders. This need was further demonstrated at a 2021 workshop held by the Grid Reliability Initiative Utilizing Data Standardization (GRIDS) Project. The GRIDS Project was established to understand and address the gaps in communication between the transmission and distribution operators. With the ongoing energy transition including electrification, distributed energy resource penetration, and so on, this project aims for improved energy emergency communications at the transmission-distribution interface.

In 2022, Winter Storm Elliott affected 60% of the United States population (Weather Underground 2022), resulting in rolling blackouts in many areas of the eastern United States (Knoxville Utilities Board [KUB] 2023). Information presented here is based on the GRIDS workshop findings and subsequent research and interviews with stakeholders. After a brief summary of the effects of Winter Storm Elliott, this report covers the standard energy emergency communications processes currently in use, how the storm affected power management operations for the Tennessee Valley Authority (TVA) and its local utility companies, and related experiences in other states. The report concludes with lessons learned and recommendations for improvements and a path forward.

2. WINTER STORM ELLIOTT

Winter Storm Elliott, referred to as a "once-in-a-generation storm" by the National Weather Service (Broderick 2023), brought high winds and record-breaking cold temperatures to most of the eastern continental United States in December 2022. The storm brought high winds and heavy snowfall to the Midwest and Northeast and high winds and freezing rain to the South. Although the storm was not a surprise to forecasters or to TVA, its intensity and speed exceeded expectations. This "perfect storm" resulted from extreme cold weather, unexpected challenges, and an unforeseen temperature drop in the Tennessee Valley of 46°F on December 23, 2023 (TVA 2023).

"There will be multiple lessons learned from last week's polar vortex that will inform future winter preparations. In addition to the load shedding in Tennessee and the Carolinas, multiple energy emergencies were declared, and new demand records were set across the continent. And this was in the early weeks of a projected 'mild' winter," NERC [North American Electric Reliability Corporation] President and CEO Jim Robb said. "This storm underscores the increasing frequency of significant extreme weather events (the fifth major winter event in the last 11 years) and underscores the need for the electric sector to change its planning scenarios and preparations for extreme events" (NERC 2022).

To understand the need for improved energy emergency communication processes, it is necessary to understand current communication processes. These processes are presented in Section 3.

3. STANDARD ENERGY EMERGENCY COMMUNICATION PROCESSES

Different systems are used for energy emergency communications across the United States. Three of the most commonly used are (1) NERC Energy Emergency Alerts (EEAs), (2) Flex Alerts, and (3) the TVA Electric Load Curtailment Program (ELCP). All of these processes include ways to accomplish three basic steps (NERC 2017):

1. Asking large industrial and commercial entities to conserve power
2. Asking the public to conserve power
3. Beginning rolling blackouts if voluntary conservation efforts are not enough

3.1 NERC ENERGY EMERGENCY ALERTS

NERC has established a standard for use of EEAs (*Emergency Operations*, EOP-011-1),[1] which can be initiated by reliability coordinators either on their own or at the request of an energy-deficient balancing authority (NERC 2017). Reliability coordinators are at the highest level of authority responsible for reliable operation of the bulk electric system and have the operating tools, processes, and procedures to prevent or mitigate emergency operating situations (NERC 2023b). Balancing authorities are typically electric utility companies responsible for ensuring that supply and demand are balanced for a portion of the power system. The US power grid comprises 66 balancing authorities, including 7 in Canada and 1 in Mexico (US Energy Information Administration 2016). The EOP-011-1 standard details the levels of alerts and responsibilities for communication but does not include specific methods for communication other than posting the current status on the Reliability Coordinator Information System (RCIS) website.[2] Three levels of alerts are used:

1. EEA 1: All available generation resources in use.
2. EEA 2: Load management procedures in effect.
3. EEA 3: Firm load interruption is imminent or in progress.

With initiation of an EEA 2 or 3, reliability coordinators and energy-deficient balancing authorities have the following responsibilities:

- **Notifying other balancing authorities and market participants.** The balancing authority communicates its needs to other balancing authorities and market participants. The respective reliability coordinator posts the declaration of the alert level, along with the name of the balancing authority on the RCIS website.
- **Declaration period.** The balancing authority updates the reliability coordinator a minimum of every hour until the EEA 2 or 3 is terminated. The reliability coordinator updates the RCIS website as

Recommendation

Standardize communication messaging and methods via Energy Emergency Alerts and Flex Alerts

Standardized communication between transmission and distribution utilities is essential for smooth, timely handling of energy-related emergencies.

[1] EOP-011-1 is being replaced by EOP-011-3, which has been approved, but the Federal Energy Regulatory Commission has deferred approving the effective date until EOP-012-1 is revised (NERC 2023a).
[2] https://nercipedia.com/glossary/reliability-coordinator-information-system/.

changes occur and passes this information on to the neighboring reliability coordinators, balancing authorities, and transmission operators.

- **Sharing information on resource availability.** Other reliability coordinators with available resources coordinate share information, as appropriate, with the reliability coordinator with an energy-deficient balancing authority.
- **Returning to pre-emergency conditions.**
    - When systems can be returned to pre-emergency conditions, the energy-deficient balancing authority requests the reliability coordinator to downgrade the alert level.
    - Via the RCIS website, the reliability coordinator notifies neighboring reliability coordinators, balancing authorities, and transmission operators that their systems can be returned to their normal limits.
    - When the energy-deficient balancing authority is able to meet its load and operating reserve requirements, it requests its reliability coordinator to terminate the EEA, who then notifies all other neighboring reliability coordinators, balancing authorities, and transmission operators via the RCIS website.

3.2 FLEX ALERTS

In addition to EEAs, the California Independent System Operator (CAISO)[3] uses Flex Alerts. Flex Alerts are requests for consumers to voluntarily conserve energy when high demand is expected and are typically issued during heat waves that drive up electricity use. Consumers are asked to reduce energy use or restrict use to times of the day or night when energy demands are usually lighter. Although the alerts are typically issued one day ahead of time to give consumers time to prepare, alerts are sometimes issued with little or no warning in response to emergencies (CAISO 2023b). Alerts can also be issued for other reasons such as peak demand forecasts, unplanned power outages, transmission line losses (e.g., because of fire), and loss of generating or transmission equipment (CAISO 2020).

3.3 TVA EMERGENCY LOAD CURLTAILMENT PROGRAM

TVA's six-step program consists of the following:

1. **Step 10: In-house load curtailment.** Utilities are requested to curtail their in-house load in offices and other facilities by turning off nonessential lighting and reducing demand for heating and air conditioning.
2. **Step 20: Voluntary load curtailment by consumers.** Distributors make efforts to supplement TVA's effort by urging consumers to voluntarily curtail electrical use (typically through the news media or other means).
3. **Step 30: Actions such as localized volt reduction to avoid firm curtailment.** TVA might lower the bus voltage at electric gate substations. Distributors curtail nonessential loads and request large-use customers and the public to do the same.
4. **Step 40: Partial curtailment of large industrial firm load.** Distributors notify industrial customers with contracted demands of 5,000 kW and higher to curtail demand within 30 minutes to only loads essential for safety and fire protection. After 30 minutes, customers are recontacted to ensure compliance.
5. **Step 50: Interruption of general firm load.** Distributors open substation feeder breakers on a rotating basis for 30–90 minutes to achieve the necessary load reduction.

[3] CAISO is a nonprofit corporation that manages the high-voltage grid for 80% of California.

6. **Step 60: Emergency tripping of firm load.** Distributors open specified low-side breakers to drop the firm load until the voltage reaches 154 kV (Memphis Light, Gas and Water [MLGW] 2022).

4. TVA RESPONSE DURING WINTER STORM ELLIOTT

4.1 HISTORIC ENERGY DEMAND

- On December 23, 2022, TVA broke its all-time record for single-day energy demand (740 GWh, or 740,000,000 kWh), as well as its highest winter peak power demand (3,425 MW).
- On December 24, TVA reached the highest weekend peak power demand in its history at 31,756 MW (compared with an average peak load of 22,600 MW) (Torres 2023).

4.2 LOSS OF GENERATION CAPACITY

- Because of the single-digit temperatures, historic demand caused a loss in generation capacity in the thousands of megawatts in TVA's portfolio on the morning of December 23.
- TVA's Cumberland Fossil Plant, which provides ~2,500 MW of power, was affected by the high winds and extreme temperatures and went offline early on December 23. Gas plants also went offline (Torres 2023).

4.3 CALL FOR REDUCED LOADS AND ROLLING BLACKOUTS

- In addition to lost power generation capacity, TVA's inability to secure power outside of the TVA system resulted in the inability to meet the power demand.
- TVA has an ELCP contract in place with each of the local power companies (LPCs) to protect the bulk electric system. All 153 electric companies are required to comply.
- On December 23 and 24, TVA ordered all 153 LPCs to reduce their load by 5%. Within 20 minutes on December 24, TVA increased this order to 10%.
- On December 23 and 24, TVA purchased an average of 5,433 MWh. "TVA's direct-serve and industrial customers, through contractual obligations and beyond, were able to reduce their consumption," TVA said (Torres 2023). Preliminary results show participants in demand response programs provided ~1,500 MW of relief during the weather event. These actions were taken before TVA implemented rolling blackouts.
- TVA issued rolling blackouts on December 23 and again on December 24.

5. POWER COMPANY EXPERIENCES WITHIN THE TVA REGION

A significant issue raised about the response in the Southeast is the lack of transparency regarding load generation and transmission. For utility companies in this region, planning for what was to come next was problematic because they did not have access to real-time data about power that would be made available to them in the near future. Executive director of the Southern Renewable Energy Association, Simon Mahan, noted that there were "real-time data on generation and load coming in from areas controlled by regional transmission organizations like PJM and MISO [Midcontinent Independent System Operator] but not so much from areas controlled by the TVA or monopoly utilities like those owned by Duke in the Carolinas and Southern Company in Alabama and Georgia" (Zullo 2023).

Recommendation

Share real-time data on generation and load sharing (i.e., for TVA and monopoly utilities in the Southeast)

Access to real-time generation and transmission data is critical for reliability.

5.1 KUB EXPERIENCE

- KUB experienced internal delays on December 23. The response to the first curtailment took 35–40 minutes because the event was unprecedented and would interrupt customers during the holidays. KUB senior leadership were quickly engaged.
- The response time to the second curtailment on December 24 was 4 minutes.

5.1.1 Issues/Lessons Learned

- Communications
    - The KUB incident command structure was not designed for the ELCP, and the internal communication process was too slow.
    - KUB hesitated to communicate with the public because there was no defined process or strategy.
    - Early communications with TVA were conflicting. KUB management reported that for planning purposes it would be good to know TVA's generation outage/status in real time. For example, as of Thursday, December 22, the TVA portal showed a low probability of curtailment for its 5-to-7-day outlook. However, TVA experienced generation issues on Friday, December 23, at 3:00 a.m. (KUB 2023).

- Technology
    - Supervisory control and data acquisition (SCADA) system control was essential for success but was a manual process.
    - The KUB customer-facing outage map was ineffective.
    - Automated metering affected the Outage Management System.
    - Automated distribution had to be disabled (KUB 2023).

In Summer 2023, KUB took the following actions to address these lessons learned by updating its ELCP program and materials and by addressing the technological challenges:

- Hired an emergency preparedness coordinator whose responsibilities include maintaining ELCP documentation, conducting annual internal ELCP exercises, and modifying the internal incident command structure specifically for the ELCP.
- Revised the ELCP plan and conducted an exercise to align KUB's strategy and process with that of TVA.
- Developed internal media content and communications templates.
- Automated the ELCP step 50 actions into the SCADA system.
- Developed procedures to disable automated meters, eliminating automated outage reports to the Outage Management System.
- Developed procedures to disable the distribution system automation (KUB 2023).

Figure 1 shows the timeline of outage-related events for KUB. Figure 2 shows the effect on KUB customers.

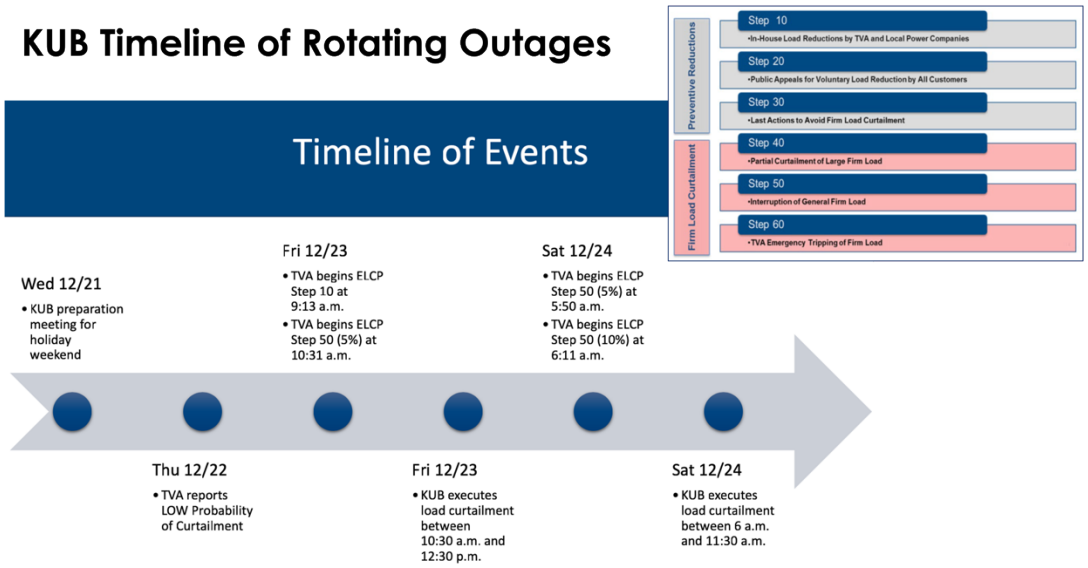

Figure 1. KUB timeline of rotating outages during Winter Storm Elliott (KUB 2023).

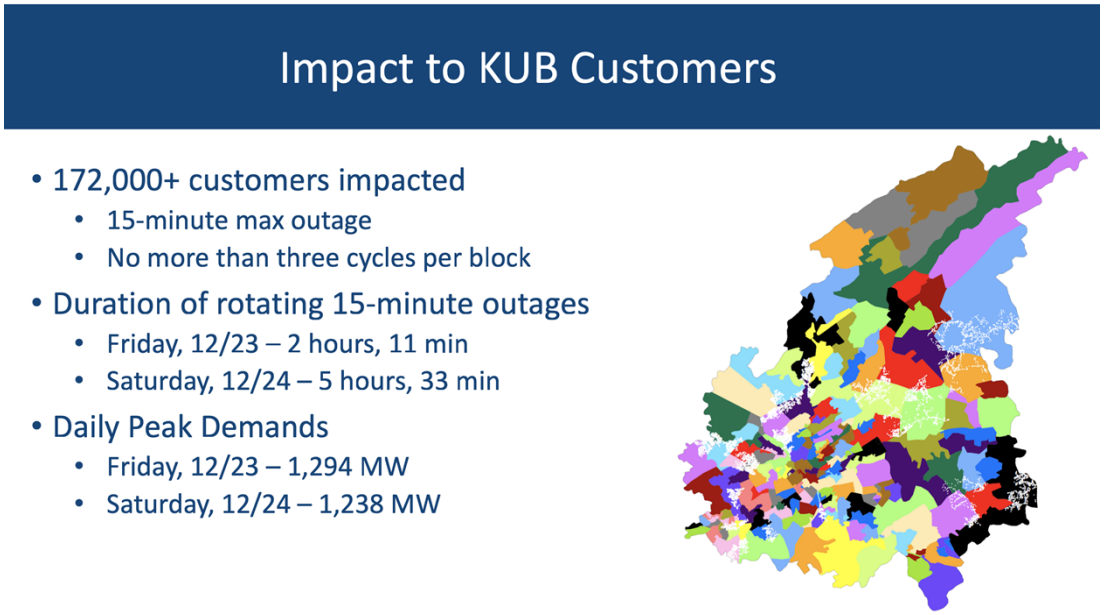

Figure 2. Effect of rotating outages on KUB customers (KUB 2023).

5.2 MLGW EXPERIENCE

As Memphis Light, Gas and Water prepared for the storm, crews were placed on standby. On the afternoon of December 22, the Electrical Crisis Response Team was put into action. When TVA ordered all 153 LPCs to reduce their load by 5%, this event was the first time the ELCP had been ordered to do so in MLGW's 89-year history with TVA.

5.2.1 Issues

- Some of the issues experienced with the blackouts were caused from the shift from 5% to 10% within 20 minutes.
- Remote control of circuit breakers worked well when opening the circuits, but in ~30% of the cases, remote closure did not work because of the extreme cold temperatures. Therefore, teams had to go to the substations to physically close the circuit breakers and restore power, which also extended the length of the outage.
- Because the storm fell on a holiday, no warning came from TVA that rolling blackouts might have to be implemented.

5.2.2 Lessons Learned

Every available resource was used to communicate with the public. MLGW will be

Recommendation

Implement advanced notification of outages as much as possible to allow better planning for restoration issues caused by extreme weather

Advanced notification of outages might enable faster response time, and utilities could put a process in place to notify personnel faster.

doing an analysis to determine where and how they can improve and will be evaluating their future plan (Chinthavali 2023).

5.3 NASHVILLE ELECTRIC SERVICE EXPERIENCE

The Nashville Electric Service (NES) distributes electricity to approximately 430,000 customers, including all of Nashville and Davidson County and parts of the six surrounding counties, covering 700 square miles. The utility maintains ~5,900 miles of distribution and transmission lines (NES 2023). NES communicates load flow and all supervisory control and data acquisition to TVA via an inter-control center communication protocol link. NES owns 161 kV lines/breakers (under TVA), and a load study is run every week using PSSE software for a 69 kV system line (Kearney 2023).

Recommendation

Automate communications about outages between power generation transmission and distribution operators

Current communications are handled manually and are sporadic. Automatic notifications about outages would give distributors more time to plan for such events and to prepare the public if necessary.

5.3.1 Issues

- TVA gave NES only an 8-minute warning about rolling blackouts on December 23.
- A fire at the Cane Ridge substation complicated matters for many residents of southeast Davidson County by creating additional outages.
- Additionally, NES was dealing with malfunctioning breakers and burning wires because of the excessive load.
- NES was busy implementing step 40 and forgot to respond to the step 40 request. Consequently, TVA called and texted to confirm that the request to take step 40 had been received. Immediately after hanging up the phone with TVA, the step 50 request came in. The quick succession of steps and extra calls and texts created confusion and took up extra time in responding to the requests.

5.3.2 Lessons Learned

- There is no method to receive advanced notices of outages.
- Having more personnel available to handle ELCP steps on the second day is helpful.
- A better understanding is needed of what caused ELCP step 50 (i.e., information on generation status).
- Better communication is needed. External communication should be faster than it was.
- A dashboard is needed for operators to better see what is happening.
    - Notifications to customers to reduce load should possibly be the LPC's responsibility.
    - Online ELCP notification and status would be better than phone calls because the NES control room is staffed with 20 system operators on a 24/7 basis who could immediately respond to notifications and updates.

5.3.3 What Went Well During the Outages

- Staff closed one circuit at a time for 15-minute outage rotations for 60% of the feeders. The other 40% was denoted for critical infrastructures, hospitals, airports, and so on, and therefore was not subject to rotating outages.
- NES was able to successfully restore power back for 17 distribution feeders within 10 minutes.

6. OTHER STATE EXPERIENCES DURING ELLIOTT

6.1 PJM

Located in Audubon, Pennsylvania, PJM is the United States' largest regional transmission organization (RTO) and coordinates wholesale electricity in 13 states and the District of Columbia. The following is a summary of events that took place during Winter Storm Elliott.

- PJM issued winter advisory and alerts beginning on December 20 through December 23.
- PJM forecasted a load demand of 127 MW, and more than 156 MW was called into the operating capacity for the day.
- The area experienced the most drastic temperature drop in a decade, and the actual load demand was more than 10% over that forecasted.
- As reserves were called in, a significant portion of the fleet failed to perform, with more than 92% of outages reported with less than an hour's notice or no notice at all.
- In addition to forced outages, ~6,000 MW of steam generation was called but was not online as expected for the morning peak on December 24. The majority of these resources (~70%) were from gas-fired plants.
- Between forced outages, derates, generators that did not start on time, and the inability to fill pumped storage hydropower ponds, PJM was dealing with ~57 GW of generator unavailability for the December 24 morning peak.

The Federal Energy Regulatory Commission and NERC are investigating the problems encountered during the storm. PJM is conducting its own investigation and plans to publish a report including recommendations and actions (PJM 2023, Kearney 2023).

6.2 MISO

MISO serves 15 US states and Manitoba, Canada. On December 23 at 5:23 p.m., MISO declared a maximum generation emergency event and increased it to a level 2 event just minutes later because of higher forced generation outages than the forecasted load. The event was terminated at 8:35 p.m. The operator declared "conservative operations" until noon on December 24 for its central and north regions, citing concerns related to "extreme cold, generation outages, and neighboring RTOs struggling to serve load" (Patel 2022). In summary, MISO had enough capacity to serve its customers without interruption. Lessons learned are related to refined winter readiness, process improvements, and improved coordination (MISO 2023).

7. LESSONS LEARNED AND RECOMMENDATIONS FOR THE PATH FORWARD

7.1 LESSONS LEARNED

- Lack of preparedness
- Lack of effective communication processes at the transmission and distribution interface
- Lack of standard procedures for communicating with power companies and residents

7.2 RECOMMENDATIONS

7.2.1 Standardize Communication Messaging and Methods via EEAs and Flex Alerts

Standardized communication between transmissions and distribution operators is essential for smooth, timely handling of energy-related emergencies. Currently, four different types of energy alerts are used across the United States: EEAs, Flex Alerts, ELCP Alerts, and public service announcements (PSAs). Although they all have similar goals, the mechanics and methodologies are different for each type of alert.

EEAs were established by NERC and are issued by reliability coordinators or balancing authorities (see Section 3.1 for details) when they expect energy deficiencies based on analysis of available and forecasted resources. EEAs are sent to other balancing authorities and market participants. Although consumers are encouraged to conserve energy, such requests are typically initiated by distribution utility companies after they receive an EEA.

Flex Alerts are used by CAISO—in addition to EEAs—and are requests for customers to voluntarily conserve electricity. CAISO issues the alerts when it expects that energy demands might exceed supply. Consumers' voluntary reduction in energy use during a Flex Alert can help prevent CAISO from being forced to take more serious steps such as emergency procedures, EEA notifications, and, eventually, rotating power outages (CAISO 2023a).

TVA's ELCP notifications are issued to ensure that TVA can meet customer demands during peak periods even if the TVA system loses its generation capabilities (MLGW 2022) or when its reserves are depleted. TVA issues alerts to utilities and distributors, who then request consumers to curtail use, often through the media (TVA 2023).

A PSA is a message that shares information to serve the public, typically regarding health or safety. Utility companies and local and regional authorities can use PSAs to reach consumers about the need to curtail energy use in times of potential crisis.

Standard procedures need to be established for the use of these different alerts to ensure timely communication and to avoid the type of miscommunication that in the past has actually caused unnecessary outages. For example, in May 2022, CAISO switched from the Alerts, Warnings, and Emergencies system to the NERC EEA system to better align their emergency levels and language with that of neighboring reliability coordinators and balancing authorities. Unfortunately, this switch created miscommunication between CAISO and personnel at the Northern California Power Agency (NCPA), the local power distributor, during heat wave events in September 2022. CAISO issued a level 3 EEA, which meant that CAISO was unable to meet contingency reserve requirements and that controlled power curtailments were in progress or were imminent. Used to receiving emergency orders under the Alerts, Warnings, and Emergencies system, however, the dispatcher understood that the request was to load shed 46.02 MW and initiate rotating power outages to prevent widespread outages. Once the outages had been started, the NCPA dispatcher contacted CAISO to let them know the curtailment action had been initiated

and was notified that a misunderstanding had taken place. NCPA immediately began returning load to the system and later issued a press release to explain why the outages had occurred (NCPA 2022).

In summary, harmonization of EEAs, Flex Alerts, ELCP Alerts, and PSAs is required for seamless communication across the nation. To adopt the best lessons learned from other regions experiencing similar events, understanding the alerting procedures of other regions and aligning them to local procedures is foundational.

7.2.2 Automate Communications about Outages between Power Generation Transmission and Distribution Operators

Current communications are handled manually and are sporadic. Automatic notifications about outages would give distributors more time to plan for such events and to prepare the public if necessary.

7.2.3 Share Real-Time Data on Generation and Load Sharing (i.e., for TVA and Monopoly Utilities in the Southeast)

As mentioned in Section 5, the lack of transparency regarding load generation and transmission was a significant issue in the Southeast region in areas controlled by TVA or monopoly utilities such as those owned by Duke in the Carolinas and Southern Company in Alabama and Georgia (Zullo 2023). For utility companies in this area, planning for what was to come next was problematic because they did not have access to real-time data about power that would be made available to them in the near future.

In TVA's *After Action Report/Winter Storm Elliott* (2023), the recommendations regarding customer and stakeholder engagement are quite general and consist of developing a "coordinated response plan, process, and templates"; ensuring "processes and information for coordination and communication"; and "centralized access to information, clearly defined roles, and execution of process." However, nothing is stated specifically about sharing real-time load generation and transmission data with utilities. Therefore, perhaps a broader-reaching standard for data sharing is needed.

One solution would be to implement mass texting around energy conservation and rolling outage notifications to electric customers. Mass texting will ensure that all utilities receive the same message at the same time and will help reduce the changes of miscommunication and varied messages throughout the relevant region.

7.2.4 Implement Advanced Notification of Outages as Much as Possible to Allow Better Planning for Restoration Issues Caused by Extreme Weather

Many instances can occur in which a scheduled 10-minute rolling outage might actually be longer because of the failed automated closing operation of switches/relays. Hence, it is important to not only communicate about planned rolling outages but also to send multiple communications about each outage because of potential restoration delays caused by other additional factors.

7.2.5 Establish Better Procedures for Communication with Residents

Experiences even before Winter Storm Elliott have demonstrated the effectiveness of utility companies requesting individual customers to reduce energy use. In 2019, for example, a polar vortex in Michigan caused reduced regional power plant output and historically high demands for natural gas. Additionally, a fire at Consumers Energy's largest natural gas storage facility disrupted the supply and delivery of natural gas. The combination of these events led to the request for conservation measures by Michigan utilities. Even though major manufacturers agreed to save energy by cutting production, the reduction in energy demand was not enough. The needed reduction in use came when the utility contacted Governor Gretchen Whitmer and the state Emergency Operation Center, and an agreement was reached to send out an emergency text message requesting consumers to turn down their heat. Said Governor Whitmer, "We knew we needed residential customers. It was important that we sent the emergency text. We had a 10-percent reduction almost immediately…That call worked, and Michiganders did their job. They saved the day" (Gray 2019).

Another example occurred in September 2022 when record extreme heat was taxing the California energy grid. The California Governor's Office of Emergency Services issued an emergency alert asking residents to conserve power. CAISO saw an immediate and significant drop in energy use. The following text message was sent through the Wireless Emergency Alerts system to cell phone users in targeted counties in areas of above-average temperatures, high population density, and high concentrations of air conditioning use: "Conserve energy now to protect public health and safety. Extreme heat is straining the state energy grid. Power interruptions may occur unless you take action. Turn off or reduce nonessential power if health allows, now until 9 p.m." The message was sent in English and Spanish (California Governor's Office of Emergency Services 2022).

Recommendation

Establish better procedures for communication with residents

Even before 2022, experience has shown that customers respond quickly and effectively to requests to conserve power.

8. CONCLUSION

Recent winter storms in the United States have demonstrated that the nationwide energy grid is not as resilient as it should be in the face of unforeseen power shortages and other emergencies. The GRIDS Project was established to research and address the weaknesses and necessary improvements in planning and communication among the transmission and distribution operators, as well as communications between stakeholders and the general public.

This report details how a predicted event such as Winter Storm Elliott can affect the US power grid in unexpected ways, creating unanticipated challenges for power management organizations and utility companies. The lessons learned included here form the basis for the recommendations presented in Section 7.

A separate observation from this study is that transmission expansion could have saved a significant amount of money during Winter Storm Elliott. Therefore, in addition to the recommendations in

Section 7, the authors recommend that a dedicated effort be made to look into how transmission expansion could best be accomplished in the near future.

In February 2023, GridStrategies issued a report for the American Council on Renewable Energy on the value of transmission during Winter Storm Elliott (Goggin and Zimmerman 2023). This report details how expanded transmission from other areas of the country to Texas and the Southeast could have not only prevented outages in those two hardest-hit regions but also saved money for all parties involved: "The large differences in power prices across regions as Winter Storm Elliott moved west-to-east across the country, plus the economic cost of outages in parts of the Southeast, indicate the value a stronger power grid could have provided during the event. This report finds that in some areas modest investments in interregional transmission capacity would have yielded nearly $100 million in benefits during the 5-day event, while most areas could have saved tens of millions of dollars."

Transmission line expansion such as Louisiana or Illinois (MISO) into TVA should be considered to allow excess wind generation to be delivered to needed areas instead of implementing curtailing: "One GW lines from neighboring Louisiana or Illinois, parts of the Midcontinent Independent System Operator (MISO), into TVA could have provided around $75 million or $79 million in value, respectively. As an influx of polar air caused record low wind chills, it also drove up wind energy output across the MISO, Southwest Power Pool (SPP), ERCOT [Electric Reliability Council of Texas], and PJM grid operating areas, driving power prices down. Unfortunately, there was insufficient transmission to deliver that wind energy to areas that needed it. It appears that on Christmas Eve morning, wind plants in parts of western MISO were forced to curtail their output while the lights went out in neighboring TVA" (Goggin and Zimmerman 2023).

The report also notes that Texas and the Southeast area expansion would have helped during Winter Storm Uri.

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