January 2025 Arctic Events

A System Performance Review

FERC, NERC, and its Regional Entities
A Joint Staff Report
April 17, 2025

Regional Entities:

MIDWEST RELIABILITY ORGANIZATION

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ACKNOWLEDGEMENT

This report was prepared by a team that consisted of staff from the Federal Energy Regulatory Commission (FERC or the Commission), the North American Electric Reliability Corporation (NERC), and its Regional Entities: Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), ReliabilityFirst Corporation (ReliabilityFirst), SERC Corporation (SERC), Texas Reliability Entity, Inc. (Texas RE), and the Western Electricity Coordinating Council (WECC), all of whom are named in Appendix 1. They were assisted by others within their respective organizations.

This is a joint staff report, and does not speak for the Commission, NERC, or any of its Regional Entities. The team would like to acknowledge and thank the ten entities that participated in the development of this report: Electric Reliability Council of Texas (ERCOT), the Florida Reliability Coordinating Council, Inc. (FRCC), ISO New England (ISO-NE), the Midcontinent Independent System Operator (MISO), the New York Independent System Operator (NYISO), the PJM Interconnection (PJM), Southeastern Reliability Coordinator (Southeastern RC), Southwest Power Pool (SPP), Tennessee Valley Authority (TVA), and VACAR-South (VACAR South). The team appreciates the feedback and cooperation of these participants in the development of this report. The team also appreciates the American Gas Association (AGA), Interstate Natural Gas Association of America (INGAA), and the Natural Gas Supply Association's (NGSA) input and thoughtful review of the report.

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EXECUTIVE SUMMARY

In February 2025, the Commission, NERC, and its Regional Entities launched a joint review of the Bulk-Power System's performance during the January 2025 arctic events, which comprised Winter Storms Blair, Cora, Demi, and Enzo.[1] The team focused on four key areas: weather conditions, operating conditions, electric grid performance, and natural gas system performance. This system performance review is backwards looking to understand what occurred and improvements made prior to and during the January 2025 arctic events; thus, this review does not assess the future performance of these natural gas and electric systems. The team engaged with ten electric entities across the Eastern and Texas Interconnections to gather the information necessary to provide a high-level overview of the Bulk-Power System's performance during the January 2025 arctic events. The team also collaborated with three natural gas associations in connection with its review.

Between January 21 and 22, 2025, natural gas demand peaked at 150 Bcf/day, electric demand peaked at 683 GW,[2] and unplanned generator outages peaked at 71,022 MW. Nonetheless, during the January 2025 arctic events, manual load shed was not required.

The team has identified improvements in generator availability and firm load shed since Winter Storms Uri and Elliott. During Winter Storm Uri in Texas and the South-Central United States, 61,305 MW of generation was unavailable resulting in 23,418 MW of firm load shed. Throughout Winter Storm Elliott, 90,500 MW of generation was unavailable resulting in 5,400 MW of firm load shed. In contrast, during the January 2025 arctic events, 71,022 MW of generation was unavailable resulting in no firm load shed. This demonstrates that during the January 2025 arctic events, the natural gas and electric systems performed well and benefitted from improved practices and procedures. The 90,500 MW of unavailable generation during Winter Storm Elliott represented a portion of the Eastern Interconnection whereas the 71,022 MW of unavailable generation during the January 2025 arctic events covered the majority of the Eastern and Texas Interconnections. Additionally, Winter Storm Uri occurred over 13 days in February 2021 whereas Winter Storm Elliott was six days in December 2022. In contrast, the January 2025 arctic events spanned 22 days. Thus, the January 2025 arctic events were longer than Winter Storm Uri and Elliott combined.

The team has several key observations, including that several participating entities set new winter peak demand during the January 2025 arctic events. The natural gas industry also met record natural gas demand and supported near record level natural gas demand for power generation using a combination of real-time production and storage during these events. In addition, the team noted steps taken to improve energy transfers and minimal natural gas production declines during the January 2025 arctic events. From these findings, the team identified notable operational practices that are detailed in Appendix 2.

The team continues to observe that the natural gas and electric systems are heavily reliant on one another to maintain reliable operations. For this reason, the team concludes that increased and further improved communication between the two is necessary to prepare for and respond to these extreme cold weather events in real-time. Nonetheless, both systems continue to see challenges from extreme cold weather conditions, exposing continued gaps. Further, both systems must continue to work collaboratively to prepare for and respond to extreme cold weather events and take into account infrastructure needs to maintain reliability and resilience. While progress has been made, both systems should continue to implement recommendations and beneficial practices, as feasible, from the Winter Storm Uri and Elliott reports as well as the December 2023 blackstart study and Winter Storms Gerri and Heather system performance review.

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1. Unless otherwise stated, this period runs from January 3 to January 24, 2025, and it will be referred to as the January 2025 arctic events throughout this report. For the purposes of this report: Winter Storm Blair takes place from January 3 to January 9, 2025; Winter Storm Cora runs from January 9 to January 12, 2025; and Winter Storm Demi/Enzo spans January 19 to January 24, 2025.

2. *See* EIA-930 generation data at www.eia.gov/electricity/gridmonitor/about.

INTRODUCTION

Over the past decade, the continental United States[3] has experienced several extreme cold weather events that have challenged the reliability of the Bulk-Power System, including the polar vortex of 2014, Winter Storm Uri in 2021, Winter Storm Elliott in 2022, and Winter Storms Gerri and Heather in 2024. The challenges to electric grid operations posed by these events have highlighted the interdependence of the natural gas and electric systems. Increased awareness of the impact of winter storms has reinforced the need for the natural gas and electric systems to continue to work collaboratively in preparation for such events.

The Commission, NERC, and its Regional Entity staff, in concert with the electric industry and in collaboration with the natural gas industry, have reviewed, analyzed, and improved electric grid operations in the wake of these winter storms. Joint reports on Winter Storms Uri and Elliott, a December 2023 blackstart availability study, and a January 2024 system performance review of Winter Storms Gerri and Heather were issued. Each joint report provided recommendations aimed at addressing and bringing awareness to the ongoing reliability and resiliency risks posed by extreme cold weather, and their impact on natural gas and electric operations.

The team found that during the January 2025 arctic events, both the natural gas and electric systems operated without major incident or manual load shed, despite some natural gas and electric entities experiencing challenges. The success in maintaining system operations without major incident was in part because both systems further improved their communication and coordination ahead of these winter storms . Based on the data and interviews that the team reviewed, electric generators appear to have performed better during the January 2025 arctic events because of additional generator commitments , improved preparedness, increased situational awareness, and the implementation of lessons learned from previous extreme cold weather events and prior report recommendations. The natural gas system also performed better overall, serving record levels of natural gas demand, and experiencing only minor production declines and short-duration *force majeure* events.

The performance of the natural gas and electric systems during the January 2025 arctic events demonstrates the benefits of actions taken in response to prior winter storm reports' recommendations, as well as the need for continued coordination in preparing for and responding to extreme cold weather. This performance also suggests that implementing the recommendations from prior reports must be sustained, year-over-year into the future to continue the required response and preparation to address the extreme cold weather impacts on the reliable operation of the natural gas and electric systems.

3. Throughout this report, references to the United States or the continental United States refer to the lower 48 states.

PROCESS AND DATA

The team from the staff of the Commission, NERC, and its Regional Entities, collectively provided the necessary planning and operations subject matter expertise to conduct this performance review.[4] The "study area" in this report refers to the electric entity areas sampled within the Eastern and Texas Interconnections.[5] While the Western Interconnection was not explicitly included in coordination with this study, in order to have a complete comparison of all the recent winter storms, the team has included data from the Western Interconnection in some of its analysis. The team sent out data requests to the ten participating electric entities across affected operating regions[6] to gauge how the applicable entities within their footprint performed during the January 2025 arctic events,[7] and later met with each of the ten electric entities. The team also reviewed relevant reports and documentation related to the January 2025 arctic events to aid in performing a more thorough review. Upon completion of the participant meetings, the team documented notable operational practices and provided analysis, as discussed below.

4. Appendix 1 lists the team members.

5. ERCOT, FRCC, ISO-NE, MISO, NYISO, PJM, Southeastern RC, SPP, TVA, and VACAR South.

6. Throughout the report, the ten participating electric entities across affected operating regions will either be referred to as electric entities or the participating entities.

7. The team sent out data requests to the ten participating electric entities across affected operating regions The team based its findings on the data available at the time that this report was published.

OBSERVATIONS

Weather Conditions[8]

The week of January 19-25, 2025 was the third coldest winter week (spanning Sunday through Saturday) across the United States since 2000.[9] The January 2025 arctic events had lower observed hourly wind chill temperatures in pockets of the Northeast, the Louisiana Gulf, California, and the Southwest compared to Winter Storms Uri, Elliott, Gerri and Heather (Fig. 1). In contrast, the coldest hourly wind chill temperatures in and around Texas were felt during Winter Storm Uri, across the Rockies and much of the eastern half of the country during Winter Storm Elliott, and in the Pacific Northwest and the northern Plains during Winter Storms Gerri and Heather. While the January 2025 arctic storms produced colder temperatures in some areas relative to other recent winter storms, the parts of the United States that experienced the coldest temperatures relative to normal conditions (25 degrees Fahrenheit or more below normal) were in Appalachia, the Rocky Mountains, the Oklahoma-Arkansas border, and Louisiana.[10] Additionally, although much of the country faced freezing temperatures and some amount of snowfall, freezing temperatures did not last as long on average as compared to Winter Storm Uri (**Table 1**) within each Region[11] and temperatures did not drop as rapidly as they did during Winter Storm Elliott (**Table 2**).

During the January 2025 arctic events, the most extreme storm relative to typical weather was Winter Storm Enzo—a Gulf and Southern storm. On January 20, 2025, a burst of snow, sleet, and freezing rain developed across Texas and Louisiana late in the day. A mixture of sleet and freezing rain fell from Austin to San Antonio and to the southernmost point of Texas. By the early morning hours of January 21, 2025, for the first time in history, a blizzard warning was issued for southwest Louisiana and southeastern most point of Texas. Snow fell in Gulf cities in Texas, southern Mississippi, southern Alabama, and western Florida. On January 21, 2025, Baton Rouge recorded 7.6 inches of snowfall, making it the city's snowiest day since recordkeeping began in 1892, while New Orleans saw its snowiest day on record, with a total of 8.0 inches.[12] Temperatures plunged to the single digits in Louisiana. Temperatures in some parts of the state fell to levels not seen in more than 125 years.

The electric entities reported varying feedback on the impact of Winter Storm Enzo. ISO-NE, NYISO, and PJM all generally described the January 2025 arctic events as having cold temperatures but overall weather conditions that were similar to a winter without a major storm. The significant characteristics of Winter Storm Enzo in the Southern and Gulf states were freezing precipitation and snow accumulation, especially in regions where those conditions rarely occur. In FRCC, only the northern portion of Florida experienced severe arctic weather including freezing precipitation and snowfall (record-setting, in some cities) which were abnormal for the region even though certain northern cities have faced cold temperatures in the past. ERCOT similarly reported that it had freezing precipitation along Southeast Texas and the Gulf Coast that tripped multiple transmission lines and had some impact on renewable resource availability. The Southeastern RC reported unusual amounts of snow on the Gulf Coast, with snowfall in Mississippi and Alabama reaching levels that had not been seen in many decades.

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8. The information contained in this section is quoted and/or paraphrased from The Weather Channel. *See generally* The Weather Channel, www.weather.com.

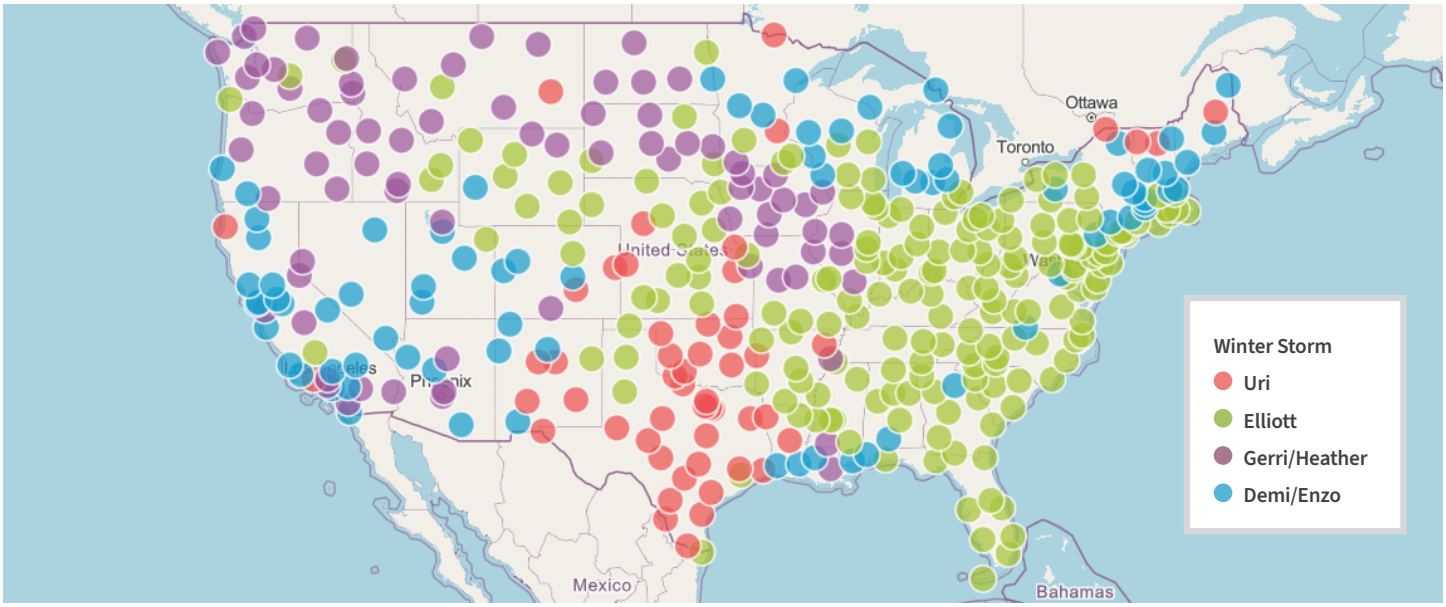
9. Weekly winter temperatures were determined by averaging hourly dry bulb temperatures at weather stations across the United States to get the average daily temperature from January 2000 through January 2025 at each weather station, averaging daily temperatures within each Sunday through Saturday period together to get the average weekly temperature at each station, then averaging those Sunday through Saturday temperatures across all weather stations.

10. *See* U.S. Maps Gridded Minimum Temperature Anomaly, National Oceanic and Atmospheric Administration, www.ncei.noaa.gov/access/monitoring/us-maps/maps?maps=.

11. *See ERO Enterprise | Regional Entities*, NERC, www.nerc.com/AboutNERC/keyplayers/pages/default.aspx.

12. Records began being recorded in 1948 for New Orleans.

Figure 1: Winter Storm with the Lowest Observed Wind Chill Temperature at each Weather Station



Source: NOAA (via Velocity Suite, © 2025 Hitachi Energy, The Velocity Suite

Figure 1 is color coded to show the winter storm—Uri, Elliott, Gerri/Heather, or Demi/Enzo—with the coldest observed hourly wind chill temperature at that weather station. Neither Winter Storm Blair nor Cora are identified in **Figure 1** because no weather station experienced its coldest hourly windchill temperature during those two storms.

Table 1: Average Consecutive Days at or Below 32 Degrees Fahrenheit

Region[13]	Uri	Elliott	Gerri/Heather	Blair	Cora	Demi/Enzo
MRO	12.49	5.71	7.24	6.45	3.58	5.81
NPCC	10.06	3.51	3.28	6.01	3.26	5.45
ReliabilityFirst	9.57	4.89	4.41	6.34	3.80	5.63
SERC	3.18	2.55	1.69	1.51	1.36	3.06
Texas RE	6.41	2.16	2.58	0.91	0.25	1.73
WECC	4.29	2.44	3.69	1.82	1.37	2.90

13. *See ERO Enterprise | Regional Entities*, NERC, www.nerc.com/AboutNERC/keyplayers/pages/default.aspx.

Table 1 reflects the consecutive number of days during each storm[14] that the average daily dry-bulb temperature was at or below 32 degrees Fahrenheit. This was calculated by taking the number of consecutive days at each weather station that temperatures were at or below freezing, then averaging those days across each weather station within a region's United States footprint.[15]

Table 2: Average 12-hour Temperature Drop to Below 15 Degrees Fahrenheit

Region	Uri	Elliott	Gerri/Heather	Blair	Cora	Demi/Enzo
MRO	21.22	29.85	21.35	17.31	15.06	22.14
NPCC	20.52	37.12	14.76	12.45	9.83	18.94
ReliabilityFirst	19.71	36.74	16.29	13.22	13.62	18.45
SERC	20.65	35.32	19.29	12.13	14.75	18.16
Texas RE	15.61	28.25	24.26	15.10	N/A	21.45
WECC	22.97	27.19	25.97	19.37	22.50	23.34

Table 2 shows the average magnitude of temperature drops to below 15 degrees Fahrenheit across a 12-hour period during each storm.[16] This was calculated by taking the maximum 12-hour dry-bulb temperature drop at each weather station, then averaging those temperature changes across each weather station within a region's United States footprint.[17]

Operating Conditions

During Winter Storms Demi and Enzo, the United States set winter records[18] in electric generation and natural gas consumption at 678 GW[19] and 150 Bcf/day[20] respectively. Electric entities that set new winter peak electric demand[21] during the January 2025 arctic events included PJM (145 GW), MISO South (33 GW), TVA (48 GW), and VACAR South (47 GW). Demand for both electricity and natural gas increase significantly and nearly simultaneously during cold weather events.

14. Winter storm dates used for this comparison are as follows: Uri (February 8-20, 2021), Elliott (December 21-26, 2022), Gerri/Heather (January 10-17, 2024), Blair (January 3-9, 2025), Cora (January 9-12, 2025), Demi/Enzo (January 19-24, 2025).
15. Data Source: NOAA (via Velocity Suite, © 2025 Hitachi Energy, The Velocity Suite).
16. Winter storm dates used for this comparison are as follows: Uri (February 8-20, 2021), Elliott (December 21-26, 2022), Gerri/Heather (January 10-17, 2024), Blair (January 3-9, 2025), Cora (January 9-12, 2025), Demi/Enzo (January 19-24, 2025).
17. Data Source: NOAA (via Velocity Suite, © 2025 Hitachi Energy, The Velocity Suite). No average temperature drop is provided if the temperature did not reach less than 15 degrees Fahrenheit.
18. Cold weather generally creates other operational challenges, such as the need to obtain and transport large volumes of natural gas and freezing issues at generating stations that are not present during the summer.
19. This is the total generation from 8 AM to 9 AM EST on January 22, 2025. *See* EIA-930 generation data at www.eia.gov/electricity/gridmonitor/about.
20. Natural gas consumption refers to residential, commercial, industrial, and power demand.
21. These peak demand values are instantaneous demand values.

Table 3: Winter Storms' Peak Hour Electricity Generation (GW) and Percentage Share of Generation Compared to Typical Winter Hours[22]

Generation Type (GW)	Typical Winter Hour	Uri[23]	Elliott	Gerri/ Heather	Blair	Cora	Demi/ Enzo
Natural Gas	169 (37%)	200 (36%)	264 (42%)	253 (41%)	256 (43%)	261 (43%)	291 (43%)
Coal	94 (20%)	161 (29%)	146 (23%)	143 (23%)	140 (23%)	132 (22%)	132 (19%)
Nuclear	94 (20%)	96 (17%)	95 (15%)	95 (15%)	98 (16%)	98 (16%)	97 (14%)
Wind	52 (11%)	29 (5%)	46 (7%)	47 (8%)	40 (7%)	51 (8%)	76 (11%)
Hydro	30 (7%)	47 (8%)	54 (8%)	41 (7%)	37 (6%)	38 (6%)	45 (7%)
Fuel Oil	1 (<1%)	2 (<1%)	13 (2%)	3 (<1%)	4 (1%)	2 (<1%)	15 (2%)
Other	8 (2%)	9 (2%)	15 (2%)	13 (2%)	7 (2%)	8 (1%)	9 (2%)
Solar	11 (2%)	10 (2%)	1 (<1%)	22 (4%)	9 (2%)	11 (2%)	5 (1%)
Storage	<1 (<1%)	N/A	N/A	N/A	2 (<1%)	1 (<1%)	2 (<1%)
Total Generation	459	553	633	616	600	607	678

Table 3 above, is intended to provide a snapshot of the generation mix at the time of the January 2025 arctic events compared to prior recent winter storms. Specifically, the table covers the generation mix in the United States for a typical winter hour.[24] Generation is shown in GW and the percentage share that each type of power provided.

As shown in **Table 3**, natural gas generation produced more electricity than any other type of generation during the January 2025 arctic events, as it has done for typical winter hours and for previous winter storms. For Winter Storms Demi and Enzo, which were the most severe of the January 2025 storms, natural gas generation provided an additional 122 GW above what has typically been observed for typical winter hours (291 GW compared to 169 GW). Coal generation also generated an additional 38 GW above its typical winter hour output (132 GW compared to 94 GW). Fuel oil generation contributed 15 GW of generation, much higher than its typical output of approximately 1 GW. Wind generation contributed 76 GW, an additional 24 GW more than it would in a typical winter hour (76 GW compared to 52 GW).[25]

22. *See* EIA-930 generation data at www.eia.gov/electricity/gridmonitor/about (noting that in some situations, balancing authorities may not have detailed information about the actual fuels used to generate electricity at dual-fuel or multiple-fuel generating facilities. When the actual fuels consumed are unknown, Form EIA-930 directs balancing authorities to report the energy source code for the primary fuel of the generator for the entire amount of generation).

23. The generation values for Winter Storm Uri and Elliott do not include load that was not able to be served or load shed. The actual demand was higher than the generation shown here, but not met due to generator outages.

24. A typical winter hour is the average of the hourly generation in any day in December, January, or February from December 1, 2020, to February 6, 2025, that is not during one of the six prior winter storms (i.e., Winter Storms Uri through Enzo).

25. From 2020 to 2023, the nameplate capacity of wind generation across the United States has increased 20 percent, which contributes to some of the wind generation increase over the typical winter hour. See EIA-860 generator data www.eia.gov/electricity/data/eia860/.

Electric Grid[26] Performance

RESOURCE PERFORMANCE

Several participating entities indicated that generators performed better during the January 2025 arctic events than in previous winter storms. For example, TVA stated that generator performance within its footprint was stable, with minimal natural gas delivery issues. Southeastern RC detailed that no major fuel-related outages occurred. FRCC noted that generator performance was strong during this period.

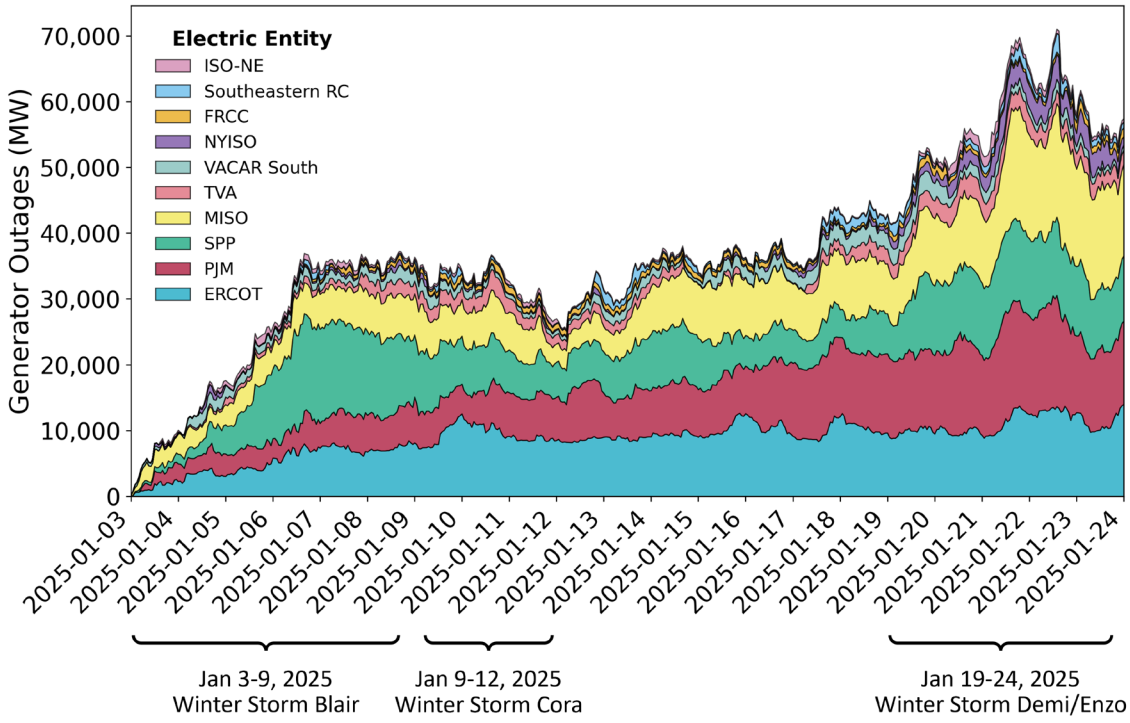
During the January 2025 arctic events, 2,444 generating units in the study area experienced 11,298 different incremental[27] forced outages, forced derates, or failures to start (unplanned outages).[28] Of those 11,298 unplanned outages across the 22-day study period, 6,853 occurred in the study area sampled within the Eastern Interconnection—compared to the 3,565 unplanned outages during Winter Storm Elliott across the 6-day period from December 21-26, 2022, in the Eastern Interconnection—and 4,445 unplanned outages in the study area sampled within the Texas Interconnection—compared to 4,124 unplanned outages during Winter Storm Uri across the 13-day period from February 8 through 20, 2021 in ERCOT, SPP, and MISO South.

26. This report considers impacts beyond the Bulk-Power System. Thus, for purposes of this report, references to the electric grid encompass all electrical infrastructure, including generation, transmission, and distribution systems.

27. "Incremental" unplanned outages refer to those which occurred during the relevant period – January 3-24, 2025, for the January 2025 arctic events. For prior winter storms, "incremental" refers to unplanned events that started December 21-26, 2022, for Winter Storm Elliott and February 8-20, 2021, for Winter Storm Uri.

28. The tally of incremental unplanned generator outages counts derates that are consecutive or "related" as separate events, when reported as such in the data. Consecutive derates at a generating unit would be one derate that ends at the same time as or one minute before another derate, that has a different derated MW magnitude, start time, or other characteristics.

Figure 2: Cumulative Incremental Unplanned Generator Outages in the Eastern and Texas Interconnections from January 3-24, 2025

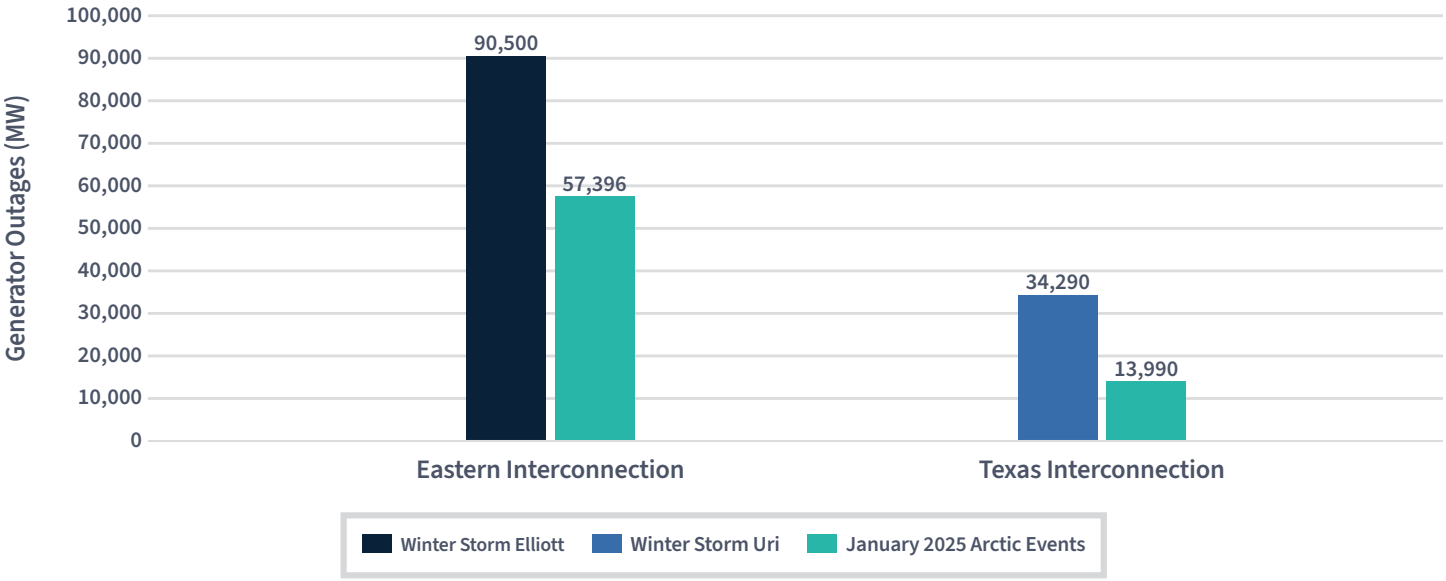


Source: 2025 January Arctic Events Data Requests

As shown in **Figure 2**, during the coldest week of the January 2025 arctic events, the number of coincident incremental unplanned outages (not including outages that started before January 3, 2025) peaked at 71,022 MW on January 22, 2025 across the study area. This is a reduction in peak coincident unplanned generator outages compared to past winter storms.[29]

29. Noting that this is not an exact comparison due to prior winter storms having different characteristics, geographic locations, duration, and resources.

Figure 3: Peak Coincident Incremental Unplanned Generator Outages (MW) During Winter Storm Uri, Winter Storm Elliott, and the January 2025 Arctic Events[30]



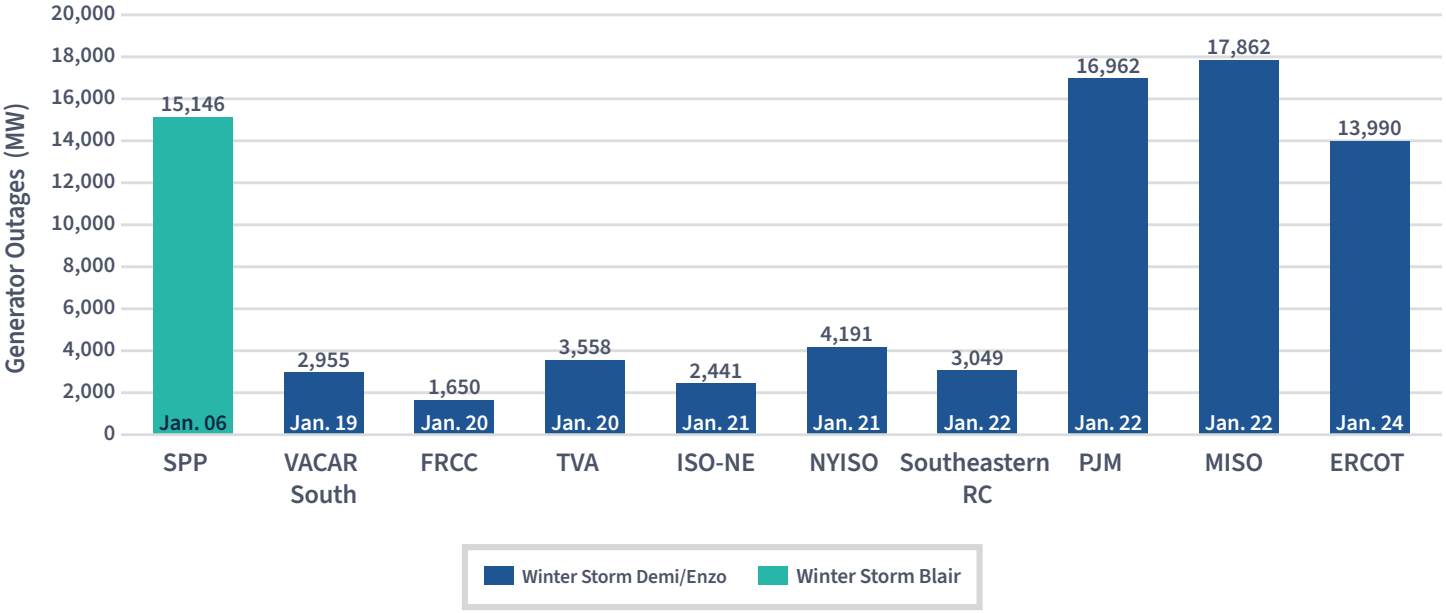
As shown in **Figure 3**, when considering only the Eastern Interconnection during the January 2025 arctic events, coincident incremental unplanned outages peaked at 57,396 MW, which is lower than the 90,500 MW of coincident incremental unplanned outages during the worst point of Winter Storm Elliott in the Eastern Interconnection study area. [31] Further, the coincident peak of incremental unplanned generation outages in the Texas Interconnection during the January 2025 arctic events was 13,990 MW , which was less than half of the 34,290 MW of incremental unplanned generator outages sampled in the Texas Interconnection during Winter Storm Uri.[32]

30. *See* FERC, NERC, and Regional Entity Staff, *The February 2021 Cold Weather Outages in Texas and the South Central United States*, at 8 (Nov. 16, 2021), www.ferc.gov/media/february-2021-cold-weather-outages-texas-and-south-central-united-states-ferc-nerc-and (November 2021 Report); *see also* FERC, NERC, and Regional Entity Staff, *Winter Storm Elliott Report: Inquiry into Bulk-Power System Operations During December 2022*, at 5 (Nov. 7, 2023), www.ferc.gov/media/winter-storm-elliott-report-inquiry-bulk-power-system-operations-during-december-2022 (November 2023 Report); January 2025 Arctic Events Data Requests.

31. *See* November 2023 Report at 5.

32. *See* November 2021 Report at 50

Figure 4: Date and Unavailable MW Value at the Peak of Coincident Incremental Unplanned Generator Outages for Each Electric Entity during the January 2025 Arctic Events



Source: January 2025 Arctic Events Data Requests

Figure 4 highlights the peak coincident incremental unplanned generator outage date as well as unavailable MW value within each electric entity. Although the peak coincident unplanned generator unavailability for the entire study area occurred on January 22, 2025, the date of greatest unplanned generator outages within each electric entity varied based on geography, storm impacts, and resource mix.

Of the 11,298 incremental unplanned outages, 4,773 outage events had a reported event cause.[33] Of those 4,773 unplanned outage events, approximately 54 percent were due to mechanical or electrical issues,[34] 23 percent were due to fuel issues,[35] 18 percent were due to freezing issues, and the remaining five percent were due to other causes.[36] This differs from Winter Storm Uri where the most common cause of unplanned outages were due to freezing issues (44 percent), fuel issues (31 percent), and mechanical issues (21 percent).[37]

During the January 2025 arctic events, some dual-fuel generators utilized alternate fuel to maintain system balance when needed. NYISO reported that generators equipped with dual-fuel capabilities were instrumental to maintaining reliable operations amid natural gas system constraints, including generators located behind city gates and served by natural gas Local Distribution Companies (LDCs). Specifically, generators in NYISO switched from natural gas to fuel oil, which helped mitigate natural gas supply constraints and increased generator availability during peak demand periods. FRCC has two

33. Event causes were only known for 42 percent of reported individual incremental unplanned generator outages at the time of data collection primarily due to the proximity between those events occurring and the time of data submission.

34. Electrical failures refer to issues such as cable failure, current transformer failure, loose electrical connections, winding failure, and overloaded electrical circuits.

35. For the purposes of this report, the team defines "fuel issues" as a generator outage event cause code comprised of all issues impacting the supply of fuel to the generating unit, including transportation, lack of fuel, fuel quality, interruptible fuel supply, and on-site and off-site fuel supply issues.

36. "Other" incremental unplanned generation outage causes include (in descending order by approximate percentage): environmental/safety issues (3.16 percent), inactive units (0.84 percent), transmission system issues (0.84 percent), personnel issues (0.21 percent), and protection system misoperations (0.01 percent).

37. *See* November 2021 Report at 15.

dual-fuel peaker plants in western Florida that are exclusively used in winter. One of these units has a 48-hour cold start-up time; therefore, ahead of Winter Storm Enzo, a balancing authority within FRCC's footprint committed and dispatched one of these peaker units ahead of time to ensure readiness. Futher, ISO-NE noted its fuel oil fleet performed well during the January 2025 arctic events.

Several participating entities also noted battery storage played a role in their successful performance during the January 2025 arctic events. Specifically, ERCOT stated that the rapid deployment of battery storage resulted in batteries providing 3,800 MW at peak times, alleviating stress on the grid during critical demand hours. Additionally, both FRCC and TVA noted that battery storage was useful when solar generation decreased or during peak demand.

COMMUNICATION

During the January 2025 arctic events, several electric entities reported better internal and external communication compared to prior winter storms. In addition, multiple electric entities stated that an increase in reliability coordinator-to-reliability coordinator calls played a crucial role in preparing for extreme weather during January 2025 and fostered greater collaboration and coordination across the Bulk-Power System. Specifically, the Southeastern RC began such calls with several reliability coordinators across the Eastern Interconnection five days prior to each of the January 2025 arctic events. In the SERC footprint,[38] reliability coordinator calls occurred daily to provide heightened situational awareness throughout the January 2025 arctic events as a direct result of lessons learned from Winter Storm Elliott. SPP noted that enhanced coordination calls with neighboring reliability coordinators provided critical insights into how the January 2025 arctic events were impacting the grid, addressed anticipated resource constraints, and identified tight operational periods. As a direct result of lessons learned from prior winter storms and report recommendations, SPP noted expanded coordination involving entities not previously included in such calls, such as the National Weather Service and Army Corps of Engineers. This enabled better visibility into the operations of the dams along the Missouri River during the January 2025 arctic events. Further, MISO conducted drills to practice communication and review procedures ahead of winter and coordinated with external electric entities such as SPP, TVA, and SERC. Miso stated that this helped it better prepare for the January 2025 arctic events. VACAR South also leveraged improved coordination with PJM, MISO, the Southeastern RC, and FRCC. And FRCC reported that daily coordination calls were held with internal entities, natural gas suppliers in Florida, the Florida Public Service Commission, and neighboring reliability coordinators.

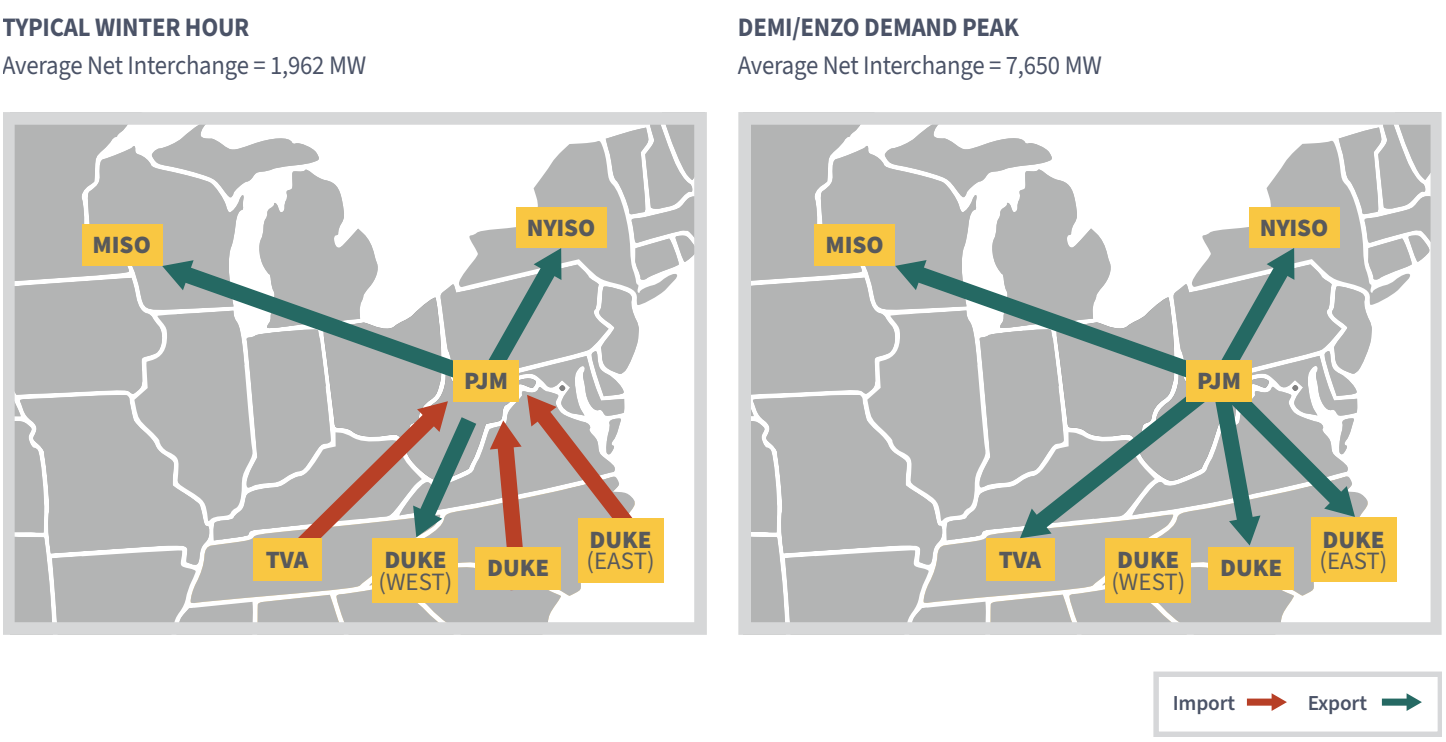
In addition to improved communications between reliability coordinators, several electric entities stated that communications with market participants and consumers in advance of and during the January 2025 arctic events also helped because these types of communications took place earlier than for prior storms. Based on market participant feedback, ISO-NE modified its morning capacity analysis report timing to provide earlier and more frequent updates, enabling its stakeholders to make more informed operational decisions, particularly during the January 2025 arctic events. NYISO updated its public system conditions page to provide greater transparency on reserve levels and conservation needs, enhancing communication with market participants and consumers during the January 2025 arctic events. ERCOT also leveraged strategic messaging from the Electric Reliability Organization leadership to emphasize the importance of preparation by market participants, explaining that messages from senior regulatory officials can influence market operating decisions. Further, FRCC used previously developed email templates and checklists to streamline timely coordination with the FRCC balancing authorities, FRCC transmission operators, the Florida Public Service Commission, SERC, and other reliability coordinators within the SERC footprint.

38. Comprised of FRCC, MISO, PJM, Southeastern RC, TVA and VACAR South.

ENERGY TRANSFERS

During extreme cold weather events, energy transfers may be used to assist neighbors in meeting energy shortfalls. Throughout the January 2025 arctic events, several electric entities reported declaring conservative operations earlier than in past events to defer, recall, or cancel planned transmission outages to reduce grid congestion and enhance transfer capability. TVA stated that it returned a key transmission line to service to strengthen the transmission system's ability, and enable PJM to transfer power to points in the southern United States. MISO requested a 345 kV transmission line back into service to improve its North-to-Central transfer capacity. FRCC used ambient-adjusted ratings for transmission lines to increase the capacity on its lines.

Figure 5: PJM Interchange During Typical Winter Hours and at Time of Maximum Demand (1/22/2025 at 8:00am-9:00am EST)[39]



As shown on **FIgure 5** above, PJM was the largest exporter of energy during the January 2025 arctic events.[40] During typical winters, PJM both imports from and exports to neighboring systems. During Winter Storms Demi and Enzo, however, PJM exported 7,650 MW to support its neighbors, while also meeting a new winter peak demand within its own footprint. During the January 2025 arctic events, there were no energy transfers between PJM and Duke West.

Since Winter Storm Elliott, TVA has prioritized securing firm transmission that covers multiple timeframes – annually, monthly, weekly, and day ahead – to ensure flexibility and availability. TVA's daily report on secured and available

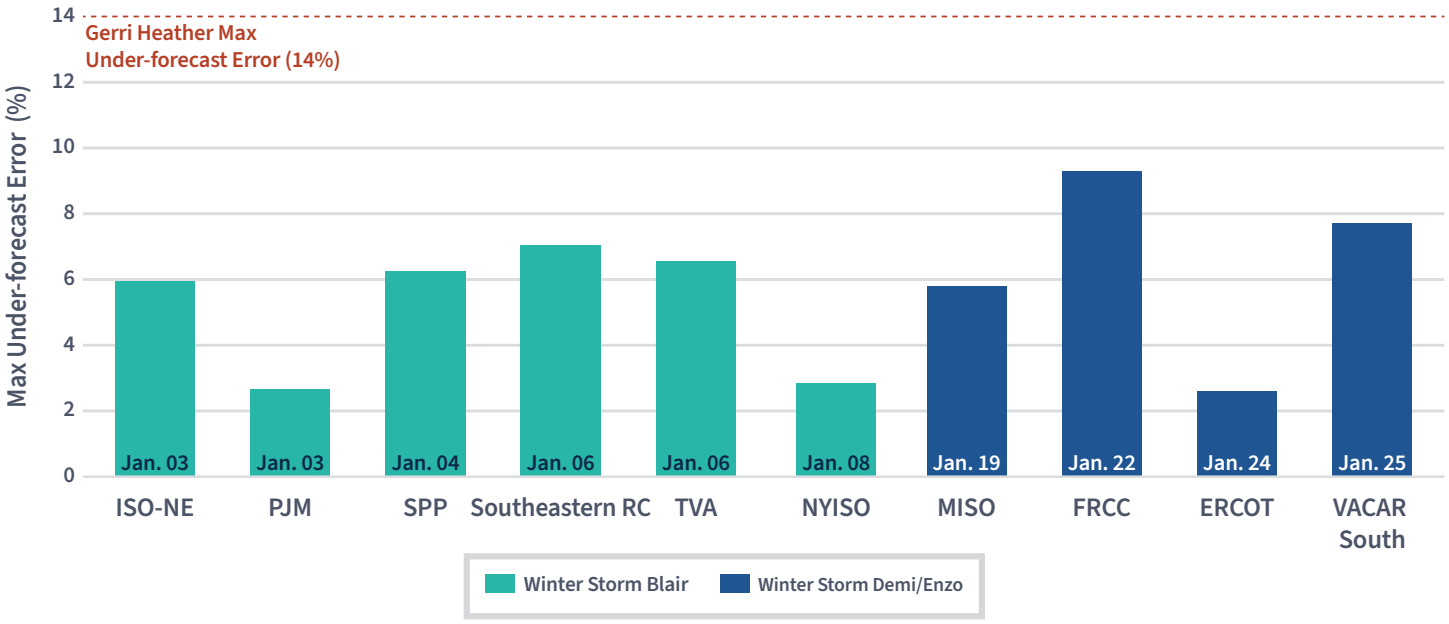
39. *See* EIA-930 generation data at www.eia.gov/electricity/gridmonitor/about.

40. *See id*.

transmission capacity supports its operational planning to reduce the risk of natural gas curtailments. Further, as with prior events, Southeastern RC ensured a large operating margin by committing all available generation in advance of the winter storms to increase the likelihood the generators would be available when needed.

LOAD FORECASTING

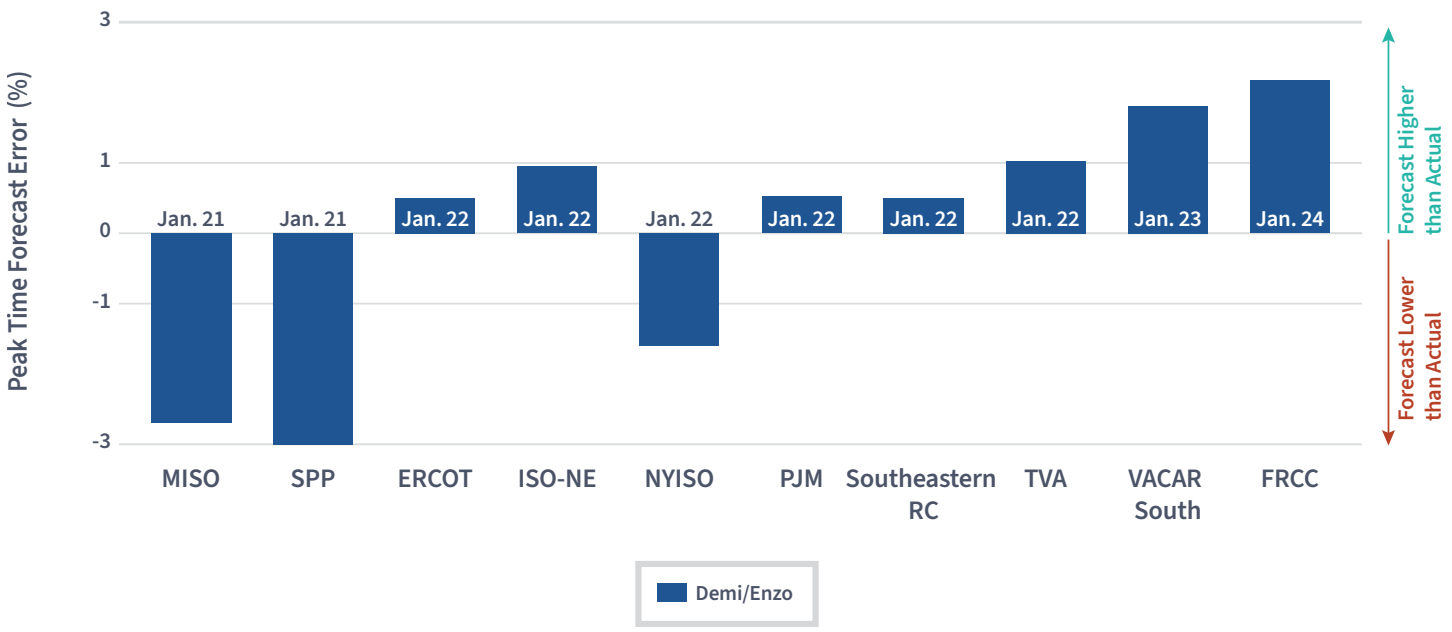
Figure 6: Largest Under-forecast Percent Error – January 2025



Sources: January 2025 arctic events data request and EIA data

Figure 6 shows the highest under-forecast (day-ahead forecast) error for each electric entity. The date label refers to the date of highest under-forecast. The date with the highest under-forecast error (when actual demand is higher than the forecast) for each participating entity for the duration of the January 2025 arctic events is shown.

Figure 7: Forecast Percent Error at Peak Demand – January 2025



Source: January 2025 arctic events data request

Figure 7 shows the day-ahead forecast error at peak demand for each electric entity. The date label refers to the date of peak demand. The figure shows the peak demand forecast error at the peak demand day for each entity, with negative bars being under-forecast and positive bars being over-forecast. All peak demand days occurred during Winter Storm Demi and Enzo. For PJM, the forecasted error ranged between 0.17 percent and 3.54 percent for the duration of the January 2025 arctic events. The largest error of 3.54 percent occurred on the Martin Luther King, Jr. holiday, which PJM attributed to altered human behavior and partial business and school closures. For the January 2025 arctic events, the participating entities stated that they were much better at forecasting than during prior storms, and notably avoided double-digit under-forecast errors that have occurred during those previous winter storms. Several electric entities noted that improved forecasting is particularly important as it minimizes the need to unexpectedly call on units in the middle of an extreme cold weather event when natural gas supplies may be limited. The participating entities typically experienced their maximum under-forecast errors early in the storms as the weather worsened. The highest under-forecast error for balancing authorities during Winter Storms Uri, Elliott, and Gerri and Heather were 11.8 percent, 12.5 percent, and 14 percent, respectively, whereas the highest under-forecast error for each participating entity during the January 2025 arctic events ranged from 9.2 percent to a low of 2.7 percent. The forecast error, less than 3 percent for all participating entities, at peak demand (between January 21-24, 2025, depending on the entity) was much lower than the point of highest error.

During interviews with the team, several electric entities stated that prior winter storm experiences have helped improve their load forecasting abilities and led to considerable reductions in forecast errors. Since Winter Storm Elliott, the load-serving balancing authority within the Southeastern RC has refined its load forecasting models by incorporating wind speed. Southeastern RC emphasized that staff experience is the biggest contributor to its forecast improvements. The Southeastern RC's day-ahead load forecast error at the time of peak demand during Winter Storm Elliott was 4.7 percent, which improved to 1.69 percent during Winter Storm Heather, and further improved to 0.5 percent during Winter Storm Enzo.[41] Elsewhere, PJM applied a risk-based approach to the load forecast, which resulted in some over-forecasting for a

41. Per EIA data, the peak demand forecast for Winter Storms Elliott, Gerri, and Heather were both under-forecast (forecast less than actual) while Winter Storm Enzo was over-forecast. *See* EIA-930 data at www.eia.gov/electricity/gridmonitor/about.

few hours of the January 2025 arctic events. In PJM the average daily load forecast error did not exceed 2.76 percent for any of the days during the events. The January 2025 arctic events included the Martin Luther King Jr. holiday weekend, which increased the uncertainty of load forecasting to accurately calculate the level of generator commitments in advance of the extreme cold weather (thereby encouraging advanced fuel procurement). Similarly, based on lessons learned from prior winter storms and report recommendations, TVA implemented enhanced coordination between their long-term and short-term forecasting teams. TVA stated that this improved alignment has reduced forecast error. Its load forecasting error dropped to 2.73 percent for Winter Storm Enzo, in contrast to 4.25 percent experienced during Winter Storm Elliott.

Several electric entities modified their methodology for load forecasting to improve their preparations for and responses to extreme cold weather. NYISO employs daily and monthly forecast reviews and continuously refines its models and makes corresponding real-time adjustments to its forecasts. Since Winter Storm Uri and other cold weather events in Winter 2020-2021, NYISO implemented a 99/1 seasonal capacity analysis,[42] adjusting parameters to better prepare for the most extreme cold weather events. NYISO stated that its forecast models performed well during the January 2025 arctic events, with a load forecasting error of approximately one percent, aligning with historical norms. Over the past two years, ISO-NE expanded its zonal-level forecasts to improve accuracy by adding more geographic diversity. ISO-NE leverages 14 different load forecast models from multiple vendors and uses weather data from 23 key locations across New England.

MISO utilized a seven-day forward reliability assessment process along with a newly developed uncertainty forecast model to identify system limitations, integrating winterization survey data and historical generator start-up times. This uncertainty quantification process allowed MISO to be better positioned, allowing for increases in short-term reserve requirements without triggering emergency procedures to procure the needed reserves. SPP used two vendors for load forecasting to provide it with multiple perspectives. Further, an entity within VACAR South incorporated real-time weather monitoring into its forecasting models, allowing for more precise adjustments to expected loads, and helping its day-ahead peak forecast error drop from ten percent in Winter Storm Elliott to less than 0.5 percent during the January 2025 arctic events. In addition, ERCOT has started using four separate weather forecasting models to improve the accuracy of its load predictions, allowing for better preparedness and operational adjustments during the January 2025 arctic events. As the impacts of extreme cold weather have grown, many electric and natural gas entities have found it beneficial to involve meteorologists in their forecasting efforts to improve forecasting accuracy.

UNIT COMMITMENTS

During the January 2025 arctic events, several electric entities reported that they started scheduling their generating units earlier than for prior winter storms. For example, since Winter Storm Uri, the Southeastern RC has placed a greater emphasis on early generator commitments with its load-serving entities initially submitting unit commitments about five days before the cold weather arrived, and now updating them daily. As a result of lessons learned and report recommendations from Winter Storm Uri, SPP implemented a pre-commitment process for baseload forecasts ahead of the natural gas purchase close dates that precede long holiday weekends. SPP stated that this process improved readiness because it provided generators with early signals to secure fuel and prepare units. PJM also anticipated limited natural gas availability due to anticipated record high demand for natural gas during Winter Storm Enzo, which occurred over the holiday weekend; as such, they pre-scheduled natural gas units to encourage generators to secure fuel supply in advance of the storm. The long holiday weekend necessitated PJM declaring conservative operations and pre-scheduling significant amounts of natural gas generation on Friday January 17, 2025. This declaration allowed generators to procure the necessary natural gas for the

42. A 99/1 analysis is based on a one percent chance that the actual system peak load will exceed the forecast value.

periods that they were needed during the Saturday 10 AM through Wednesday 10 AM period. In a similar vein, generators in ERCOT procured adequate fuel and self-scheduled leading into the events.

TVA reported that during the January 2025 arctic events, it committed all available units before the events and staggered generator start times. TVA also dispatched units for reliability, keeping generators online at lower output levels to avoid potential start-up issues related to cold weather, even though the economics would otherwise warrant turning the unit off. Further, TVA stated that its standard practice is to have 24-hour in-person natural gas support staff liaisons between the generators and the balancing authority during extreme cold weather events. TVA established this practice after Winter Storm Elliott.

During the January 2025 arctic events, several electric entities reported an increase from prior winter storms in deferring or cancelling planned generator outages to maximize generator availability. Additionally, PJM issued a maintenance outage recall[43] on January 15, 2025, effective January 19, 2025, ensuring that planned generator outages did not interfere with reliable system operation during Winter Storms Demi and Enzo.

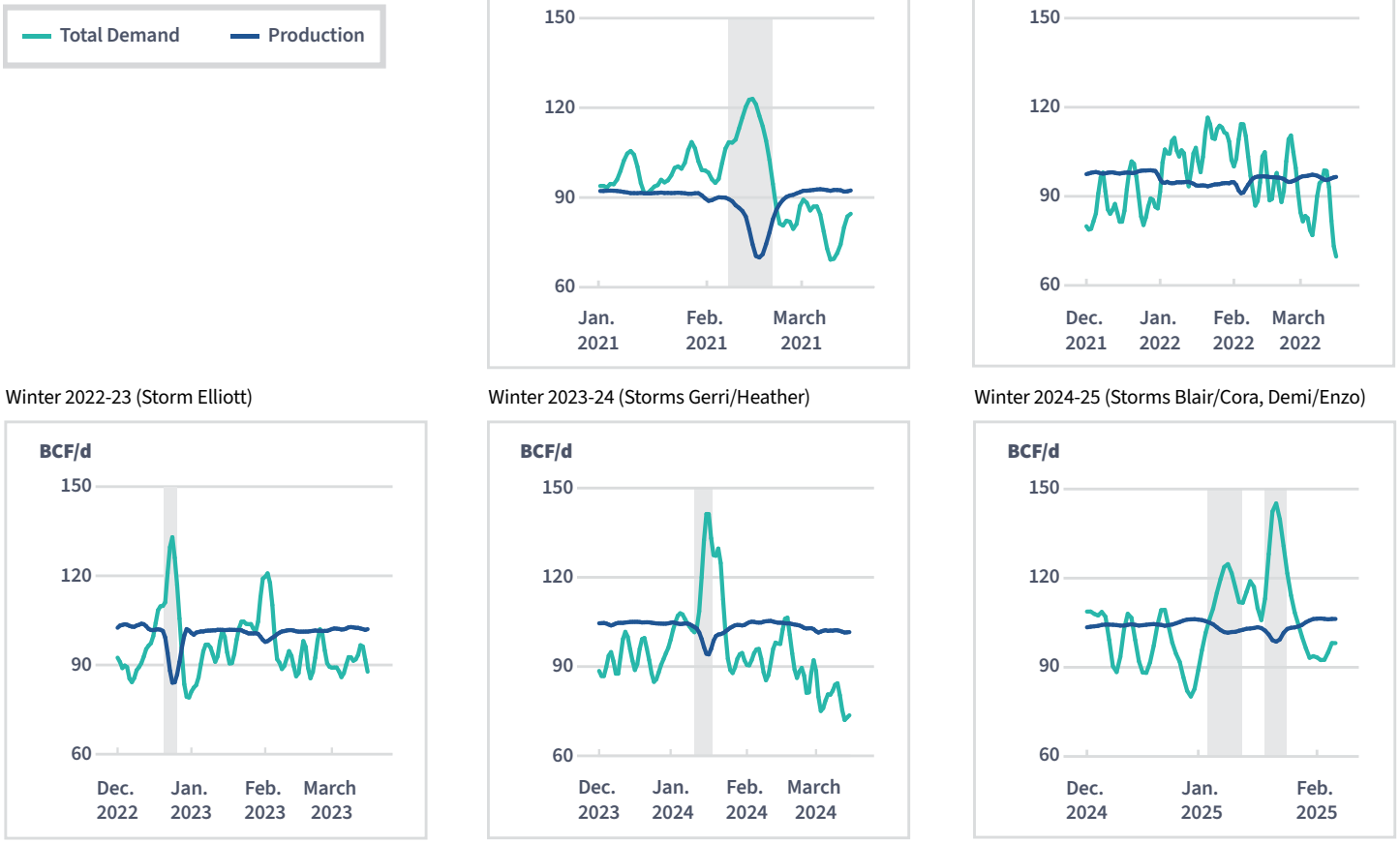
43. A maintenance outage recall refers to a situation where a company, such as PJM, issues a recall for all active generator maintenance outage tickets within specific regions. This means that member companies have a limited time (72 hours) to end the maintenance outages.

Natural Gas System Performance

NATURAL GAS DEMAND AND PRODUCTION

During the January 2025 arctic events, the natural gas industry met record natural gas demand and supported record-breaking natural gas power demand using a combination of real-time production and storage. As discussed below, natural gas storage continues to play a critical role in supporting reliability during extreme cold weather.

Figure 8: Winter Natural Gas Production and Demand[46]



The graphs above in **Figure 8** compare dry natural gas production for the United States with residential, commercial, power, and industrial demand over the last five winter seasons. The gray shaded areas indicate severe cold weather events – Winter Storm Uri in 2021, Winter Storm Elliott in 2022, Winter Storms Gerri and Heather in 2024, and the January 2025 arctic events. As shown in the above charts, while natural gas production dropped during the winter 2024-2025 extreme cold weather events, total demand rose significantly. This exemplifies the critical role that natural gas storage plays in meeting total natural gas demand and thereby supporting reliability during extreme cold weather.

44. *See* S&P Global Commodity Insights. © 2025 by S&P Global Inc.

COMMUNICATION AND COORDINATION

Natural gas and electric industry coordination is essential in preparing for and responding to extreme cold weather conditions. During the January 2025 arctic events, interstate natural gas pipelines appear to have issued more proactive and more frequent notices, including Operational Flow Orders (OFOs)[45] to communicate with their customers and electric industry stakeholders (e.g., RTOs/ISOs, balancing authorities, reliability coordinators, etc.), compared to prior winter storms. During the artic events, FRCC noted that natural gas pipeline personnel participated in its situational awareness calls to better coordinate on natural gas inventories, compressor station availability, and pipeline readiness. Though initially developed for hurricanes and extreme heat rather than extreme cold, FRCC has maintained long-standing relationships with Florida's natural gas suppliers. As such, FRCC keeps a list of two contacts at each natural gas supplier for redundancy and verifies those contacts regularly. During the January 2025 arctic events, FRCC noted several units approached their maximum burn limitations under their contracts and pipelines issued OFOs . However, FRCC's heightened natural gas supplier communications helped it to maintain situational awareness and effectively prepare for and respond to the OFOs.

MISO has actively built relationships with natural gas pipeline operators through in-person meetings held by the pipelines that helped to facilitate proactive communication during severe weather. Because of those relationships, during the January 2025 arctic events a natural gas entity contacted MISO directly on the weekend to communicate operational developments. MISO also participates with other ISO/RTOs on the ISO-RTO Council Electric Gas Coordination Task Force to address relevant issues that may arise on the system. TVA noted that it has strong, existing relationships with natural gas suppliers. In one instance, these relationships helped it to procure the natural gas that was needed during the Martin Luther King Jr. holiday weekend. Some entities within TVA and VACAR South shared natural gas-fired generator burn profiles with natural gas pipelines as much as five days in advance of the January 2025 arctic events and provided hourly burn rates to the pipelines, so the pipelines had more granular details about the future gas needs of the natural gas-fired generators. This information sharing, in turn, allowed the pipelines to better prepare, for example, by increasing line pack. As part of typical winter operations, PJM's Gas Electric Coordination Team conducts weekly calls with all of the interstate natural gas pipelines within its footprint to review current and anticipated loads, system conditions, and operational risks. PJM increases the frequency of these calls when operational risks increase, as occurred during the January 2025 arctic events. During these high-risk periods, PJM personnel maintain a 24 hour, 7 days a week communication with key natural gas pipeline personnel to maintain ongoing real-time awareness of conditions. Additionally, PJM conducts regular updates with LDC personnel to assess potential natural gas supply interruptions of natural gas-fired generators located behind the LDC city gates. Since Winter Storm Elliott, PJM has also increased communication with several upstream natural gas producers and the Marcellus Shale Coalition to gain a better understanding of their preparations in advance of cold weather conditions.

Interstate natural gas pipelines continue to be a key facilitator of communication across the natural gas and electric industries. Pipelines regularly hold customer and stakeholder meetings entering the winter seasons and some hold more frequent coordination phone calls in advance of some storms. Natural gas industry associations similarly have task forces and forums aimed at continuous improvement, education, and communication with electric entities during cold weather events, such as the newly created Natural Gas Readiness Forum that was an outgrowth of the National Association of Regulatory Utility Commissioners' Gas-Electric Alignment for Reliability initiative.[46] In addition to the communications discussed above, pipeline notices continue to be a critical source of real-time information, providing insight not only into

45. An Operational Flow Order is a mechanism to protect the operational integrity of the pipeline. It requires shippers to balance their natural gas supply with their customers' usage. This can impact shippers by limiting their flexibility when demand varies over the course of a day.

46. *See AGA Hosts Inaugural Natural Gas Readiness Forum to Improve Energy Reliability*, AMERICAN GAS ASSOCIATION (Dec. 2024), www.aga.org/news/news-releases/aga-hosts-inaugural-natural-gas-readiness-forum-to-improve-energy-reliability/.

pipeline operations, but potential issues at specific receipt and delivery points related to natural gas production, natural gas-fired generation, and residential, commercial, and industrial natural gas consumption.

Despite improvements in gas-electric coordination, natural gas system communications in some regions of the country are inconsistent, and the frequency and quality of communications can vary by the type of entity. For example, ERCOT noted that it has limited communication with natural gas suppliers in its footprint because intrastate entities do not have the same standards for information transparency that interstate pipelines have.[47] It stated that further developments with communication, including improved familiarity with industry terminology across the natural gas and electric industries, is needed.

TRANSPORTATION

Natural gas pipelines declared several *force majeure* events on interstate pipelines in Louisiana, Wisconsin, and Michigan during the January 2025 arctic events, but they were relatively short in duration and had limited impacts on the Bulk-Power System and natural gas systems. MISO maintained awareness of the generators potentially impacted by the *force majeure* declarations and relied on updated offer information submitted by the asset owners and market participants through normal and well-established processes and procedures as part of its overall risk assessment and unit commitment processes. VACAR South noted it benefited from the Mountain Valley Pipeline, which reached full capacity in January 2025 for the first time since it became operational in June 2024.[48] VACAR South indicated that the pipeline played a crucial role in maintaining reliable electric supply during this high demand period by sustaining stable pipeline pressure. Compared to prior winter storms, PJM noted that it faced a relatively minor level of natural gas disruption. PJM stated that these disruptions were driven primarily by lack of firm transportation capacity, interruptions by LDCs, and a few localized gas compressor station issues. PJM reported that the availability of onsite backup fuel, in many of these cases, helped to mitigate losses.

STRATEGIES TO MITIGATE NATURAL GAS MARKET ILLIQUIDITY

As noted above, the Martin Luther King Jr. holiday weekend presented a challenge for some participating entities. However, Southeastern RC stated that in some ways, the long holiday weekend worked to its advantage, as the shortened natural gas procurement period forced generators to commit early. This may have presented more of a challenge for natural gas purchasers to manage even though early commitment provided the grid operators with a higher degree of natural gas generator availability due to fuel certainty. Entities within the Southeastern RC conducted fuel procurements well in advance, often through multi-year contracts years in advance of the January 2025 arctic events, with a strong emphasis on securing firm supply and transportation contracts for natural gas and ensuring that backup fuel (such as fuel oil) was fully replenished ahead of this period. TVA noted that it has both firm and non-firm transportation contracts with pipelines to access natural gas from geographically dispersed basins, mitigating the risk of one basin being impacted by extreme weather. Although firm transportation contracts ensured pipeline availability, TVA also used interruptible transportation to supply its natural gas-fired generators. In addition, TVA relied on contracts with two physical storage facilities in Louisiana and Mississippi, plus "virtual storage" options such as "park and loan" services

47. *See* FERC, NERC, and Regional Entity Staff, *Blackstart and Next-Start Resource Availability in the Texas Interconnection,* at 25-26 (Dec. 2023), www.ferc.gov/sites/default/files/2023-12/Blackstart Report.pdf.

48. See *MVP Runs Full, Gives Appalachia Natural Gas Prices More Exposure to Winter Demand Spikes*, Natural Gas Intelligence (Jan. 9, 2025), www.naturalgasintel.com/news/mvp-runs-full-gives-appalachia-natural-gas-prices-more-exposure-to-winter-demand-spikes/.

on three pipelines, to navigate natural gas market liquidity issues and maximize flexibility.[49] TVA stated that its long- and short-term storage strategies provided additional natural gas availability.

PJM reported that the long holiday weekend covering four gas days (10 AM EST Saturday through 10 AM EST Wednesday) meant that a large number of natural gas-fired generators needed to procure natural gas by Friday morning. If generators did not procure and schedule natural gas on Friday, they risked the likelihood that supply would become increasingly scarce during the weekend on an intraday basis. Correspondingly, the possible scarcity increased the risk of natural gas units being unavailable to operate. Exposure to the weekend intraday gas market also introduced the potential for illiquidity and increased price volatility. To help mitigate this risk, PJM declared conservative operations and pre-scheduled certain resources early Friday morning with expected output at various times through Wednesday morning the following week. While this was successful in mitigating risks related to natural gas generators acquiring gas commodity, PJM stated that this pre-scheduling was done using five-day load forecasts.

49. Park and Loan services are interruptible services that allow customers the flexibility to temporarily store their gas on a pipeline system for later use or to borrow gas from the pipeline system and pay it back later.

ANALYSIS

Electric Grid Performance

The team observed that the participating entities have many practices and procedures pertaining to extreme cold weather generator performance, communication protocols, energy transfers, load forecasting, advanced unit commitments, and natural gas operations that enhance their preparations and responses to extreme cold weather. The team believes that these implemented operating practices led to improved outcomes compared to prior winter storms. Incorporating these operational practices,[50] where it can be done practically, effectively and efficiently, could further increase the reliability of the grid during extreme weather events. Between January 21 and 22, 2025, natural gas demand peaked at 150 Bcf/day, electric demand peaked at 683 GW,[51] and unplanned outages peaked at 71,022 MW. Nevertheless, during the January 2025 arctic events, manual load shed was not required. Factors that could have potentially led to improved performance to mitigate the impact of the unplanned generation outages include: scheduling additional generation and having adequate reserves, energy transfers, and coordination between natural gas and electric entities.

Weatherization: Improvements to generator weatherization supported reliable operations during the January 2025 arctic events. Since the 2014 polar vortex, entities within the Southeastern RC have placed a greater emphasis on heat trace monitoring and plant readiness in advance of extreme cold weather. The team believes that by putting more time and effort into ensuring that equipment has the proper winterization measures, generating units will be less likely to freeze and fail to perform during extreme cold weather. ERCOT stated that the Texas state rules for generator winterization align closely with Reliability Standard EOP-012 (Extreme Cold Weather Preparedness and Operations) on generator winterization; as such, ERCOT believes that its generators should be able to comply with certain requirements of the Reliability Standard earlier than its mandatory and effective date.[52] Several participants also reported that they already implemented Reliability Standard EOP-012, which they believe led to better performance during the January 2025 arctic events.

Communication and Coordination: The improvements to communication and coordination practices demonstrated before and during the January 2025 arctic events show that natural gas and electric entities are implementing lessons learned and report recommendations from prior winter storms to improve operations during extreme cold weather events. Following Winter Storm Elliott, the Southeastern RC focused on auditing and improving its communication processes by preparing message templates, refining its notification timing, and enhancing its coordination internally and with external stakeholders. The team believes that this increased communication with a larger array of entities and consumers allowed for streamlined, better prepared real-time responses during extreme cold weather conditions. The load-serving balancing authority within the Southeastern RC also conducts a winter preparedness drill once a year, incorporating situational scenarios and Energy Emergency Alert simulations. It stated that interest in these drills has grown, with increased participation from neighboring electric entities. The team believes that not only does this drill add insight into anticipated resource constraints, but expanding the number and types of entities involved fosters greater communication and collaboration that can span across regions. PJM noted that it has a new process to manually contact at-risk, non-dual fuel natural gas-fired generators during cold weather advisories or alerts to verify natural gas supply availability. The team believes that this process helps natural gas and electric entities increase their situational awareness and therefore make better informed decisions about unit commitments during, and in anticipation of, extreme cold weather events. In addition, during the January 2025 arctic events, MISO, for the first time, sent natural gas

50. The notable operational practices are listed out in Appendix 2 below.

51. *See* EIA-930 generation data at www.eia.gov/electricity/gridmonitor/about.

52. Reliability Standard EOP-012-2 became mandatory and effective on October 1, 2024. Nevertheless, electric entities have time to comply with certain requirements at later dates.

delivery scheduling reminders to generator owners ahead of the holiday weekend. Given the illiquidity of the natural gas market and availability concerns that may materialize during holiday weekends, the team finds that doing so helps ensure that better preparations are made in advance of any extreme cold weather holiday period. TVA implemented a stakeholder engagement "playbook" that facilitates improved coordination between utilities, natural gas suppliers, and regulatory bodies. This playbook has improved its external communication and situational awareness, earning positive stakeholder feedback.

Operations Staffing: In advance of the January 2025 arctic events, the Southeastern RC temporarily doubled its normal operational staff personnel levels. While Southeastern RC has characterized this as a standard practice in advance of extreme weather events, the team believes this is a notable and useful operational practice to help ensure that electric entities have the proper resources to prepare for and respond to an extreme cold weather event. After Winter Storm Uri, ERCOT hired full-time staff with natural gas system experience to improve its understanding of natural gas system operations and how it impacts grid operations to facilitate gas-electric coordination on an ongoing basis. The team finds that this is a beneficial operational practice that facilitates the coordination and understanding between the electric and natural gas systems during extreme cold weather events.

Blackstart Unit Availability: During the January 2025 arctic events, blackstart resource unavailability was less of an issue as compared to Winter Storms Uri and Elliott. From January 3-24, 2025, blackstart units experienced unplanned generator outages that resulted in the unavailability of 116 MW from 14 blackstart units in the Texas Interconnection and 2,240 MW from 98 blackstart units in the Eastern Interconnection. In contrast, during Winter Storm Uri, there was just under 750 MW of generator unavailability within the Texas Interconnection.[53] Further, throughout Winter Storm Elliott, there was just over 5,000 MW of generator unavailability from 155 blackstart units within the Eastern Interconnection.[54]

For enhanced situational awareness into blackstart availability, the Southeastern RC stated that it has an energy management system that monitors blackstart availability and issues an alert when a blackstart unit goes out of service, as well as identifies an alternate unit to dispatch. The Southeastern RC adopted this practice ten years ago in partial response to a North American Transmission Forum recommendation. The team believes that this is a beneficial operational practice because it provides entities with a heightened real-time awareness of blackstart unit availability.

Fuel Surveys: Several balancing authorities and reliability coordinators reported that fuel surveys are an important aspect of their extreme cold weather preparedness efforts. NYISO stated that it conducts an annual fuel survey for all its units and a weekly survey for its thermal units that track firm natural gas contracts and on-site available fuel inventory. This process was initially developed after the 2014 polar vortex and subsequently improved upon based on lessons learned from Winter Storms Uri and Elliott. NYISO also issues ad hoc surveys on an as-needed basis to obtain real-time situational awareness of fuel availability. ISO-NE performs an annual pre-winter generator readiness survey that is issued by November 1, with responses due by December 1, and conducts periodic generator fuel and emission surveys, which monitor fuel inventory levels, fuel replenishment plans, and environmental limitations. The Southeastern RC stated that fuel procurement within its footprint is closely monitored. MISO stated that it tracks dual-fuel units at registration and surveys its single-fuel coal and oil units' fuel as well as its consumables inventory and environmental limitations every three weeks. MISO can increase the frequency of these surveys if it feels the need. The team believes that annual and routine fuel surveys and/or obtaining fuel procurement information within any given footprint is a beneficial operational practice because it ensures greater transparency and insight into anticipated generator availability and potential constraints or limitations.

53. *See* November 2021 Report at 236-37.

54. See November 2023 Report at 105-06.

Normal/Conservative Operations: During the January 2025 arctic events, FRCC declared conservative operations for the impacted portion of its footprint while maintaining normal operations in the rest of its footprint. In order to recall transmission line outages, FRCC has to be in conservative operations. This was the first time FRCC implemented such a bifurcated approach, and it provided it with the ability to recall transmission lines on outage to provide impacted areas with access to external energy. FRCC noted, and the team agrees, that this is a beneficial operational practice that could be used for future extreme cold weather events to ensure continued normal operations in less impacted areas while still providing extra support to impacted areas.

Resource Availability Risk Assessment: After Winter Storm Elliott, PJM implemented new processes, such as using its Generator at Risk Tool, which assesses the risk of projected temperatures on generator performance based on cold weather operating limits (and was created after Winter Storm Gerri to allow such insight). The team believes that this type of generator risk assessment is a beneficial operational practice that allows entities to make more informed decisions on unit commitments and increase awareness into resource availability. Efforts by PJM to improve visibility into generator preparedness include joint site visits with ReliabilityFirst and increased winter preparedness data requests and surveys. The joint site visits include an overview of procedures and walk downs to inspect equipment. The team believes that these efforts represent beneficial operational practices that increase situational awareness during extreme cold weather. The fuel surveys described above could provide a key input to such assessments.

Natural Gas Procurement, Scheduling and Transportation Strategies: TVA implemented natural gas planning processes, including daily morning and evening calls to review natural gas transportation strategies, as well as 24-hour on-site support from gas scheduling teams who act as liaisons between the natural gas companies and the balancing authority. The team believes that such coordination and communication with natural gas entities is a beneficial operational practice because it increases overall situational awareness in extreme cold weather. Given that the electric and natural gas entities are heavily reliant on one another to maintain operations during extreme cold weather, this level of collaboration is key to helping ensure more reliable performance.

After Winter Storm Uri, ERCOT introduced Firm Fuel Supply Service, which compensates generators for maintaining on-site fuel storage. Although this service was not used during the January 2025 arctic events, the team believes that it represents a proactive step towards enhancing grid resilience. ISO-NE implemented an Inventoried Energy Program in the 2023/2024 and 2024/2025 winters that provided incremental compensation to certain resources that maintained inventoried energy during the winter months to enhance fuel security.[55] NYISO[56] and ISO-NE[57] are engaging its stakeholders on a market rules proposal to implement a firm fuel capacity accreditation program, which should provide increased insight into expected generator availability in advance of extreme weather events. Additionally, MISO implemented seasonal capacity market reforms in 2024 that MISO believes contributed to improved cold weather performance by incentivizing winterization investments.

Southeastern RC stated that the largest load-serving entity in its footprint requires firm fuel contracts, which it considers to be an assurance measure. Non-firm natural gas transportation is more likely to be curtailed during extreme cold weather events, reinforcing the importance of obtaining firm pipeline capacity. While the team recognizes that firm natural gas supply and transportation contracts may not be available or feasible for every entity, when practicable, they mitigate fuel availability risks during an extreme cold weather event. During the January 2025 arctic events, NYISO encouraged a few dual-fuel generators to conserve fuel oil reserves by operating on natural gas, even when not economical, thereby helping to manage alternate fuel levels over the holiday weekend. This approach can be a beneficial operational practice if natural gas

55. *See Inventoried Energy Program*, ISO-NE, www.iso-ne.com/markets-operations/markets/inventoried-energy-program.

56. *See Capacity Accreditation*, NEW YORK ISO, www.nyiso.com/accreditation.

57. *See Capacity Auction Reforms Key Project*, ISO-NE, www.iso-ne.com/committees/key-projects/capacity-auction-reforms-key-project.

is available because it helps ensure the sustained generation capability of dual-fuel units. Further, NYISO reported that during the January 2025 arctic events, securing barge deliveries for fuel oil on short notice became increasingly challenging. NYISO also stated that the availability of ultra-low sulfur diesel may become a localized supply chain issue in New York as generators transition to cleaner fuels, although this was not an issue in January 2025.

The natural gas and electric industries rely heavily on one another to maintain operations during extreme cold weather events. As such, collaboration is needed between the two industries for timely, efficient, and effective preparations and real-time responses. While some of this improved performance may be a result of the weather being less severe, improvements and beneficial practices arose from the January 2025 arctic events. Nevertheless, the team reinforces that natural gas and electric entities should continue to implement the recommendations from prior winter storm reports to further improve their preparations and response to extreme cold weather events.

Natural Gas System Performance

During the January 2025 arctic events, the overall impact of Winter Storms Blair and Cora on the natural gas system was relatively minor. Winter Storms Demi and Enzo brought colder weather, causing domestic natural gas demand to spike to record levels above 150 Bcf/day on January 21, 2025.[58]

During Winter Storm Uri, natural gas production for the United States dropped to as low as 69 Bcf/day, representing a decline of approximately 25 percent from normal production, 83 Bcf/day during Winter Storm Elliott, representing a decline of approximately 18 percent, and 92 Bcf/day during Winter Storms Gerri and Heather, representing a decline of about 12 percent.[59] At its January 21, 2025 low point, production levels dipped to approximately 97 Bcf/day, representing a decline of less than eight percent from average production levels in December 2024. This was the case even as the United States experienced record peak natural gas domestic consumption during the January 2025 arctic events.

58. Refers to residential, commercial, industrial, and power demand.

59. Based on dry natural gas production from S&P Global for the United States, compared to the average daily production for the calendar month prior to each event. See S&P Global Commodity Insights. © 2025 by S&P Global Inc.

Figure 9: Natural Gas Production Declines[60]

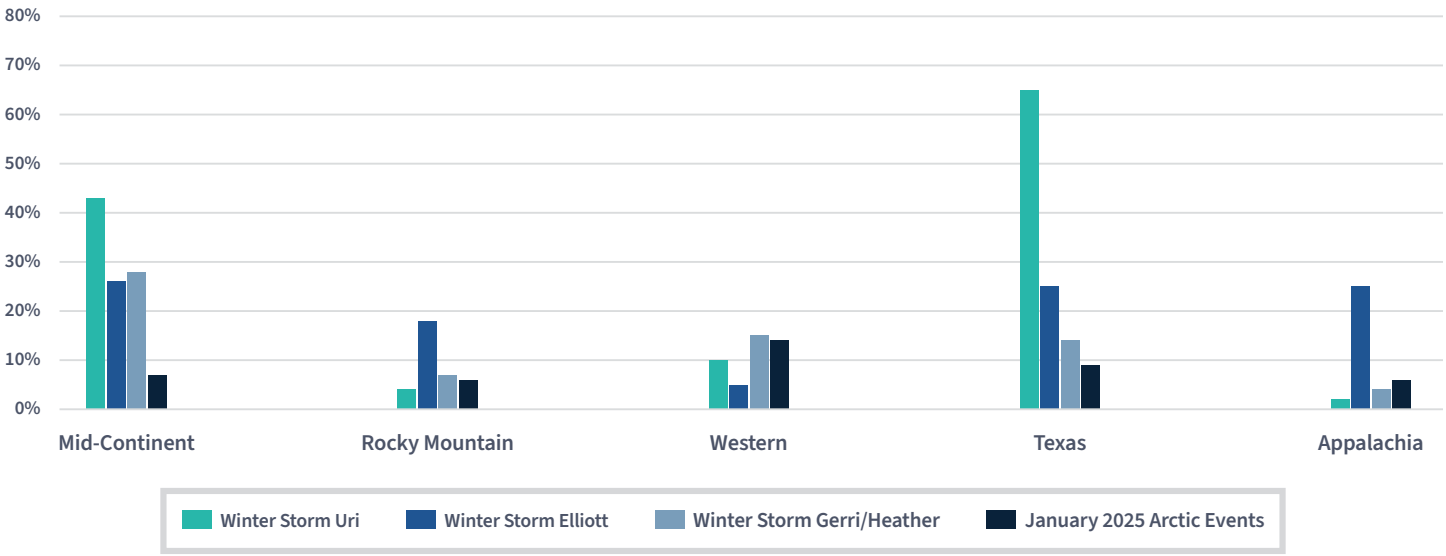


Figure 9 compares the lowest daily production level for each recent winter storm dating back to Winter Storm Uri with the average production levels in each region in the month prior. Not every storm impacted every region equally, but Winter Storm Uri had a disproportionate impact on Texas and the Mid-Continent regions. In contrast, Winter Storm Elliott hit Appalachian production the hardest. As such, production performed comparatively better during the January 2025 arctic events than in Winter Storms Uri and Elliott.

During the January 2025 arctic events, the total production loss was much less significant than during the previous storms and mostly occurred during Winter Storms Demi and Enzo between January 19, 2025, and January 24, 2025. For example, PJM noted natural gas production in Appalachia dropped five percent (2 Bcf/day), which was significantly lower than the 11 Bcf/day loss seen during Winter Storm Elliott. Not only were the production losses lower compared to prior winter storms, but the duration of the losses was much shorter compared to prior winter storms.

The natural gas market was able to meet record demand, with natural gas infrastructure – including wellheads, gathering, processing, pipeline transportation, and local gas distribution – performing adequately during the January 2025 arctic events. The natural gas system appears to have experienced fewer disruptions than during Winter Storms Uri and Elliott and did not have widespread freezing, mechanical, or production loss issues. This is partially because temperatures did not drop as low as forecasted, avoiding potentially significant production declines from long concentrated extreme cold over the South Central and Appalachian production regions. However, several other factors also contributed to the overall positive performance, including advanced preparation, incorporating lessons learned and report recommendations from past winter storms, diversity of fuel supplies, and natural gas storage.

In advance of the January 2025 arctic events, many interstate natural gas pipelines issued weather and operational notices, in addition to implementing their normal cold weather preparations. Pipelines generally held and attended customer stakeholder meetings, held phone calls with shippers, and communicated with RTOs/ISOs and other stakeholders in the electric industry. While pipeline operational notices are common practice, the detail and frequency of these informational notices appears to have increased for many electric entities since Winter Storm Uri. These notices

60. *See* S&P Global Commodity Insights. © 2025 by S&P Global Inc.

generally alerted shippers to the fact that incoming cold weather might have an operational impact on the natural gas transportation system. As a result, shippers should pay particular attention to both its natural gas receipts and deliveries, making sure to stay in balance (meaning that shipper should only take off the amount of natural gas that it had put onto the pipeline). Each pipelines' tariff dictates the extent to which shippers may be "out of balance" as well as the penalties incurred for exceeding the tariff's limits. Under OFOs, shippers generally incur penalties if their takes exceeded two to three percent of their firm entitlements.

During the January 2025 arctic events, the natural gas system was aided by significant storage withdrawals, on par with week-level peaks seen during Winter Storms Elliott, Gerri, and Heather. According to the Energy Information Administration (EIA), net natural gas storage withdrawals reached 223 Bcf for the week ending on January 17, 2025, and 321 Bcf for the week ending on January 24, 2025. EIA also reported that due to the large storage withdrawals, natural gas inventories fell to four percent below the five-year average at the end of January 2025.[61]

During the January 2025 arctic events the natural gas system performed well. While some of this improved performance may be a result of the weather being less severe compared to prior winter storms, natural gas entities appear to be showing continuous improvement from prior winter storm experiences on its cold weather performance, preparations, and communications. Natural gas entities should continue to find ways to improve their cold weather preparations and real-time communications with stakeholders during extreme cold weather events.

Continuing Gaps

As noted above, natural gas and electric industry coordination continues to be necessary to address the challenges of preparing for and responding to extreme cold weather. While the participants reported some improvements in natural gas and electric coordination, gaps remain. The team identified several notable operational practices in Appendix 2 below to address these gaps.

As improvements, we note that several natural gas pipelines have increased their issuances of critical notices pertaining to upstream receipt point impacts. Similarly, many electric entities improved its coordination with natural gas suppliers. Nonetheless, transparency issues persist, particularly concerning real-time fuel availability. Multiple electric entities continue to face challenges in obtaining operational impact data from natural gas producers and suppliers, limiting visibility into supply constraints. ERCOT stated that enhanced state regulatory support and data-sharing initiatives with natural gas producers and state-level natural gas entities could improve transparency and situational awareness. The team believes that continued improvements into the real-time transparency in fuel supply reporting would be helpful.

Some electric entities advocate for increased operational information sharing regarding fuel supply and increased liquidity of natural gas during long weekends when multi-day natural gas commitments are the norm. While bilateral gas trading exists over extended holiday periods, it can still be a challenge for most of the participating entities if they need to acquire natural gas supply or transportation on short notice during long holiday weekends. This is why most electric entities found it necessary to procure natural gas in the standard four-day holiday weekend strip in advance of the holiday weekend during the January 2025 arctic events. Due to scheduling and timing differences between the natural gas and electric markets, PJM encountered significant uncertainty and challenges associated with the ability of natural gas generators to acquire additional supply and transportation capacity.

61. *See Recent Cold Snap Results in Fourth-Largest Withdrawal from Underground Natural Gas Storage*, U.S. ENERGY INFORMATION ADMINISTRATION (Feb. 10, 2025), www.eia.gov/todayinenergy/detail.php?id=64524.

Additionally, FRCC stated that while the timing misalignment between the electric and natural gas markets remains a concern, FRCC has operational practices in place to help address this issue, including inviting natural gas contacts to reliability calls for updates on the state of the natural gas system. These reliability-focused discussions ensure compliance with codes of conduct by excluding marketing personnel from operational discussions. Some electric entities stated that the establishment of an officially published natural gas trading hub price over each weekend day could potentially increase liquidity, spur greater daily trading of natural gas supply, and improve alignment with the electric industry. However, even if natural gas supply can be procured, finding available pipeline transportation capacity during a cold weather event may still be difficult in certain areas of the country.

Despite the overall adequate grid performance during the January 2025 arctic events, a critical and persistent gap remains: mechanical and electrical generator outages. This trend reinforces the urgency of implementing recommendations from past cold weather event reports, including Uri Report Recommendation 11 and Elliott Report Recommendation 2.[62] The continued prevalence of these outages suggests that existing preparations may be insufficient or inconsistently applied, indicating a need for a more robust approach to continued winter preparedness. Namely, these causes accounted for approximately 54 percent of generator outages with a reported outage cause. The recurrence of these issues across multiple extreme weather events points to a systemic vulnerability in generator fleet resilience that has yet to be fully addressed. Without action and before the relevant entities must comply with the entirety of Reliability Standard EOP-012, the risk of mechanical and electrical failures compromising grid reliability during future cold weather events will persist.

Some electric entities have implemented pay-for-performance measures, or a seasonal capacity market, that they believe resulted in improved generator performance. Further, some electric entities highlighted significant improvement in their load forecasting techniques. Yet, electric entities have also indicated that challenges persist when accounting for growing distributed energy resources. ISO-NE noted that the quality of irradiance forecasts[63] remains an issue due to limited research in this area and also indicated that improvements in solar forecasting would improve load forecasting, including the impact of 6,000 to 7,000 MW of behind-the-meter solar in ISO-NE's footprint. As such, the team believes that further refinement of load forecasting models could further improve operational planning and grid resilience.

While the natural gas system appeared to show improvement during the January 2025 arctic events, the team reinforces that more collaboration and communication between the natural gas and electric industries is needed to prepare for and respond to extreme cold weather. As such, the natural gas and electric entities should continue to implement the recommendations from prior winter storm reports and studies.

62. *See* November 2021 Report at 215 (stating that Recommendation 11 noted that generator owners should analyze mechanical and electrical systems not directly susceptible to freezing but which suffered failures during extreme cold weather to assess the impact of extreme cold weather on such mechanical and electrical components); *see also* November 2023 Report at 134-35 (noting that recommendation 2 stated that NERC should initiate a technical review of the individual causes of cold weather related unplanned generation outages caused by mechanical or electrical issues during Winter Storm Elliott to identify the root cause of such failures to reduce the frequency of such outages during extreme cold weather events).

63. Irradiance forecasting refers to the process of predicting solar irradiance levels, which are essential for the efficient integration of solar energy into the grid. It involves various methods and techniques to forecast solar irradiance at different horizons, ensuring reliability.

CONCLUSION

During the January 2025 arctic events, the natural gas and electric systems performed well, as measured by no manual load shed, and benefitted from improved practices and procedures. Nevertheless, both systems continue to see challenges from the extreme cold weather conditions, exposing continued gaps. The impact of these winter storms has reinforced the need for the natural gas and electric systems to continue to work collaboratively to prepare for and respond to extreme cold weather to improve reliability and to take steps to ensure there is adequate infrastructure in place to support electric reliability. The Commission and NERC staff are working together to track the progress of the Winter Storm Uri and Elliott recommendations.[64] While progress has been made, the natural gas and electric systems should continue to implement recommendations and operational practices, as feasible, from the Winter Storm Uri and Elliott reports as well as the December 2023 blackstart study and the January 2024 Winter Storms Gerri and Heather system performance review.

64. *See Reliability Spotlight: Cold Weather Preparedness*, Federal Energy Regulatory Commission, www.ferc.gov/ReliabilitySpotlight.

APPENDIX 1: TEAM MEMBERS LIST

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APPENDIX 2: NOTABLE OPERATIONAL PRACTICES

The list below summarizes the operational practices discussed by the team in the report itself that the team believes led to improved outcomes as compared to prior winter storms. More details are available in the body of the report.

1. Putting more time and effort into ensuring that equipment has the proper winterization measures in place lowers the risk of generating units freezing during extreme cold weather.

2. Increased and improved communication with a larger array of entities and consumers brings with it streamlined, better-prepared real-time responses during extreme cold weather conditions.

3. Manually contacting at-risk natural gas generators (non-dual fuel) during cold weather advisories to verify natural gas supply availability can help an entity increase its situational awareness to make more informed decisions on unit commitments during extreme cold weather.

4. Sending natural gas delivery scheduling reminders to generator owners ahead of a holiday weekend helps ensure that better preparations are made before natural gas market liquidity becomes an issue.

5. Joint site visits with Regional Entities in advance of extreme cold weather help entities prepare for winter operations.

6. Increasing the number of operational staff during an event contributes to an entity having the proper resources to prepare for and respond to extreme cold weather.

7. Incorporating staff with natural gas system experience can help improve an electric entity's understanding of natural gas system operations and how natural gas operations impact grid operations.

8. Having an energy management system that monitors blackstart resources can provide an entity with a heightened real-time situational awareness into blackstart availability.

9. Annual fuel surveys and obtaining fuel procurement information contributes to greater transparency and insight into anticipated resource availability and constraints ahead of extreme cold weather.

10. Expanding the number and types of entities involved in winter preparedness drills add insights into anticipated resource constraints and fosters an increase in communication and collaboration that could span across regions.

11. Declaring conservative operations for the impacted portion of a footprint while maintaining normal operations in the rest of a footprint could be beneficial in times of stressed conditions.

12. Implementing a generator risk assessment helps entities make more informed decisions on unit commitments and increases awareness of resource availability ahead of extreme cold weather.

13. Firm natural gas supply and transportation contracts, where feasible, help reduce the risk of fuel unavailability during an extreme cold weather event.

14. Implementing a natural gas planning process with increased communication and a 24-hour onsite staff liaison increases the overall situational awareness of fuel availability in advance of and during extreme cold weather.