Fleetwide Failures: How Interregional Transmission Tends to Keep the Lights on When There Is a Loss of Generation[1]

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I. Overview

Resilience of the US power grid is a foundational building block for the safe, reliable, and secure delivery of electricity across the country. Our grid, however, is subject to an increasing variety and magnitude of threats, both natural and man-made, which can serve to interrupt generation resources and much needed service to load centers. What's more, researchers have found that correlated, unplanned generator outages are present in most NERC regions and represent a significant resource adequacy risk.[2] All generation resource types can be affected by unplanned outages, whether the events are caused by an extreme weather event or even a targeted attack on the grid.

The US power grid boasts over 600,000 circuit miles of transmission lines, approximately 240,000 of which are intra and interregional high-voltage transmission lines.[3] Events that interrupt generation tend to be more localized, allowing for regions to call upon these interregional transmission lines to import electricity from regions experiencing different weather patterns to cancel out local fluctuations in electricity supply and demand. A region can also take advantage of ties between regions to export electricity to avoid renewable curtailments as well as manage internal congestion and transmission flows. In a sense, interregional transmission ties are the "lifelines" that keep the grid up and running when these types of interruptions occur. Despite the role interregional transmission plays in supporting grid resiliency, annual regionally planned transmission investment in RTOs/ISOs has decreased steadily over the last decade.[4]

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[1] This report was not commissioned by any entity but is related to work for various clients interested in clean energy and reliability.
[2] Murphy, Apt, Moura, and Sowell, *Resource Adequacy Risks to the Bulk Power System in North America*, Carnegie Mellon Electricity Industry Center Working Paper, (n.d.); Murphy and Sinnot, *Correlated Generator Failures and Power System Reliability*, Carnegie Mellon University, 2019.
[3] Edison Electric Institute, "Transmission," (n.d.)
[4] Gramlich and Caspary, *Planning for the Future: FERC's Opportunity to Spur More Cost-Effective Transmission Infrastructure*, at 25, January 2021.

In a Commission-led proceeding on grid resilience, grid operators and experts highlighted the importance of interregional transmission during threats to the system:

- NYISO: "[R]esiliency is closely linked to the importance of maintaining and expanding interregional interconnections, [and] the building out of a robust transmission system."[5]

- ISO-NE: "The system's ability to withstand various transmission facility and generator contingencies and move power around without dependence on local resources under many operating conditions . . . results in a grid that is, as defined by the Commission, resilient."[6]

- PJM: "Robust long-term planning, including developing and incorporating resilience criteria into the [Regional Transmission Expansion Plan], can also help to protect the transmission system from threats to resilience."[7]

- SPP: "The transmission infrastructure requirements that are identified through the [Integrated Transmission Plan (ITP)] process are intended to ensure that low cost generation is available to load, but the requirements also support resilience in that needs are identified beyond shorter term reliability needs. For example, the ITP identified the need for a number of 345 kV transmission lines connecting the panhandle of Texas to Oklahoma. These lines were identified as being economically beneficial for bringing low-cost, renewable energy to market, but their construction has also supported resilience by creating and strengthening alternate paths within SPP."[8]

- Brattle Group analysts: "The power system can be vulnerable to disruptions originating at multiple levels, including events where a significant number of generating units experience unexpected outages. The transmission system provides an effective bulwark against threats to the generation fleet through the diversification of resources and multiple pathways for power to flow to distribution systems and ultimately customers. By providing customers access to generation resources with diverse geography, technology, and fuel sources, the transmission network buffers customers against extreme weather events that affect a specific geographic location or some external phenomenon (unavailability of fuel and physical or cyber-attacks) that affect only a portion of the generating units."[9]

This report documents numerous instances of broad failures of generation, beyond what is considered in typical capacity markets or integrated resource plans (which typically assume all

[5] *Response of the New York Independent System Operator, Inc.*, Docket No. AD18-7, at 4, March 9, 2018
[6] *Response of ISO New England Inc.*, Docket No. AD18-7, at 15, March 9, 2018.
[7] *Comments and Responses of PJM Interconnection, L.L.C.*, Docket No. AD18-7, at 49, March 9, 2018.
[8] *Comments of Southwest Power Pool, Inc. on Grid Resilience Issues*, Docket No. AD18-7, at 8, March 9, 2018
[9] Chupka and Donohoo-Vallett, *Recognizing the Role of Transmission in Electric System Resilience*, at 3, May 9, 2018.

generator outages are independent of one another). When some event affects a broad set of generation in an area, this "common mode failure" is often not incorporated into generation capacity planning, but should be incorporated into interregional transmission planning because as many ISO/RTOs have said, interregional transmission often saves the day by sharing resources from one area with another.

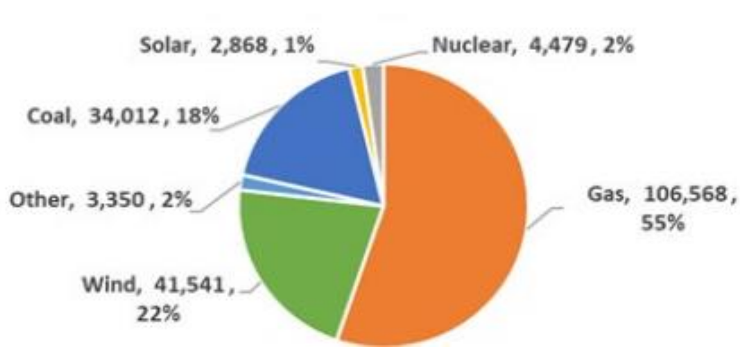
A closer look at a handful of recent ex post extreme weather event analyses from RTOs and ISOs demonstrates how outages can affect a wide range of generation resource types. Data from these analyses and the U.S. Energy Information Administration's "Hourly Electric Grid Monitor"[10] also provide a snapshot of imports and exports to and from affected regions over the event time frames, which tells the compelling story of how interregional transmission helps keep the lights on when local supply is unavailable and demand spikes.

II. Recent Extreme Weather Event Examples

a. Winter Storm Uri (February 2021)

The extreme cold weather event affecting Texas and other parts of the Central US during the week of February 14, 2021 led to the most unplanned cold weather-related generation outages of any cold weather event in the area in the last decade. According to the FERC, NERC and Regional Entity Joint Staff Inquiry, ERCOT experienced capacity outages from generating units of all fuel types averaging 34,000 MW for two consecutive days – nearly half of its 2021 all-time winter peak load of 69,871 MW.[11] Unplanned outages and derates for the entire event area reached 192,818 MW, as shown in Figure 1 below:

Figure 1: Fuel type of generating units that experienced unplanned outages and derates (by MW of nameplate capacity), total event area[12,13]



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[10] U.S. Energy Information Administration, "Hourly Electric Grid Monitor," last accessed November 23, 2021.

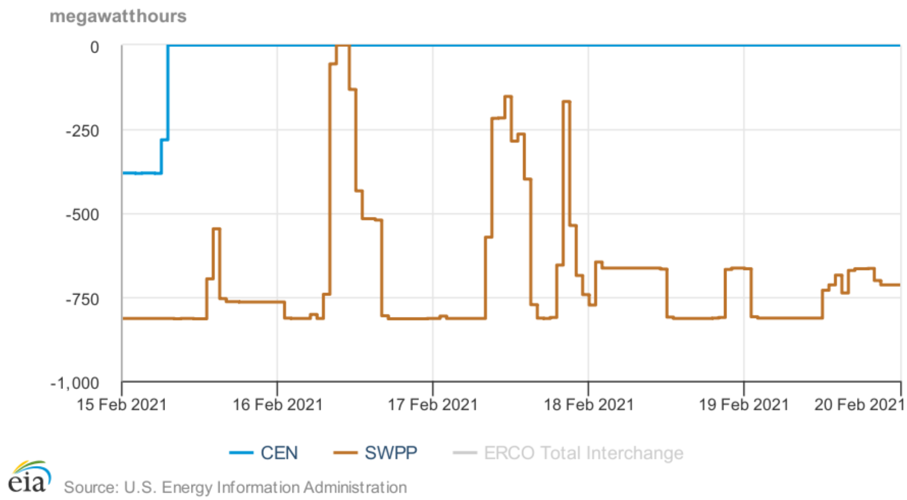
[11] FERC, NERC, and Regional Entity Joint Staff, *February 2021 Cold Weather Grid Operations: Preliminary Findings and Recommendations*, at 5, last updated September 23, 2021.

[12] *Ibid*.

[13] It would be more appropriate to use accredited capacity rather than nameplate capacity.

Due to a lack of interregional ties, ERCOT was only able to import approximately 800 MW of power from SPP during the week of the cold snap, as shown in Figure 2 below.[14] SPP experienced shortfalls itself, as demonstrated by the spikes on the 15th and 16th, which were exacerbated due to the scheduled outages of three of seven western interconnection DC ties – Eddy County, Blackwater, and Rapid City.[15] ERCOT was able to import an additional 400 MW from Mexico up until the 15th, when Mexico experienced natural gas supply shortages.

Figure 2: Electric Reliability Council of Texas, Inc. (ERCO) electricity interchange with neighboring balancing authorities 2/15/2021-2/19/2021, Eastern Time



While MISO and SPP also experienced similar cold weather conditions, those RTOs were able to import electricity from other regions experiencing milder temperatures. For example, at maximum, MISO was able to import approximately 9,000 MW from PJM, a few thousand MW from the Tennessee Valley Authority (TVA), and a combined 3,000 MW from Southern Company, Louisville Gas and Electric and Kentucky Utilities Company, and Canada. As a result of its interregional capacity, MISO was able to import a total of 13,000 MW during the peak of the event - about 15 times as much power as ERCOT was able to import. MISO was also able to export 5,000 MW and 2,500 MW to SPP and Associated Electric Cooperative Incorporated, respectively, over the course of the cold snap.[16]

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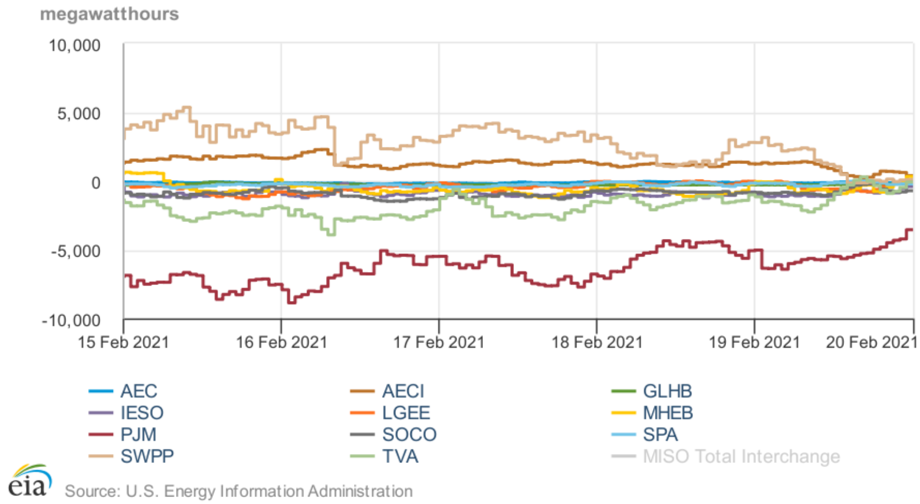
[14] Goggin, *Transmission Makes the Power System Resilient to Extreme Weather*, at 8, July 2021.
[15] SPP, *A Comprehensive Review of Southwest Power Pool's response to the February 2021 Winter Storm*, at 68, July 19, 2021.
[16] Goggin, *Transmission Makes the Power System Resilient to Extreme Weather*, at 8, July 2021.

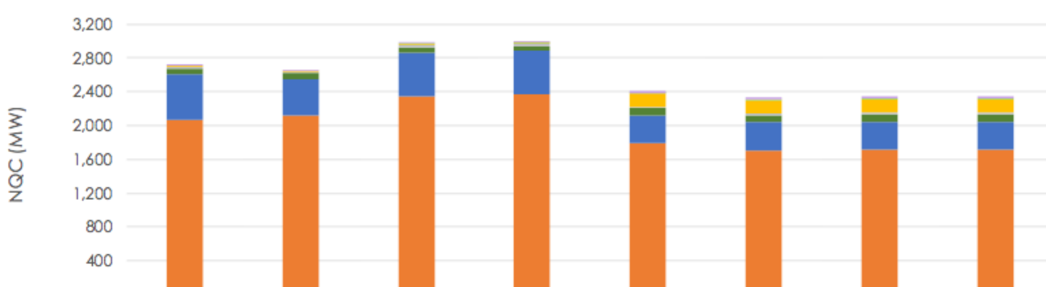
Figure 3: Midcontinent Independent System Operator, Inc. (MISO) electricity interchange with neighboring balancing authorities 2/15/2021-2/19/2021, Eastern Time



b. CAISO Extreme Heat Wave (2020)

On August 14-15, 2020, CAISO experienced a "1-in-30-year" weather event that forced the grid operator to institute rotating electricity outages throughout the state. As shown in figure 4 below, net qualifying capacity (NQC) outages over the two-day event ranged from 2,333 to 2,996 MW and impacted a variety of resources. Most of these outages, however, were natural gas units, as thermal resources were derated or taken offline by the high temperatures.

Figure 4: CAISO resource adequacy outage snapshot during 2020 heat wave (August 14-15)[17]



	8/14, Stage 2 (3:25 pm)	8/14, Peak (4:56 pm)	8/14, Stage 3 (6:38 pm)	8/14, Net demand peak (6:51 pm)	8/15, Peak (5:37 pm)	8/15, Stage 2 (6:16 pm)	8/15, Net demand peak (6:26 pm)	8/15, Stage 3 (6:28 pm)
Other	10	5	7	7	27	26	26	26
Wind	0	0	13	13	6	6	6	6
Solar	6	7	7	7	155	155	155	155
Import	29	19	29	29	20	29	29	29
Geothermal	69	69	60	60	79	79	79	79
Hydro	535	424	508	509	336	335	335	335
Natural gas	2,070	2,123	2,352	2,371	1,788	1,704	1,714	1,714
Grand total	2,719	2,647	2,976	2,996	2,411	2,333	2,344	2,344

[17] CAISO, *Root Cause Analysis: Mid-August 2020 Extreme Heat Wave*, at 87, January 13, 2021

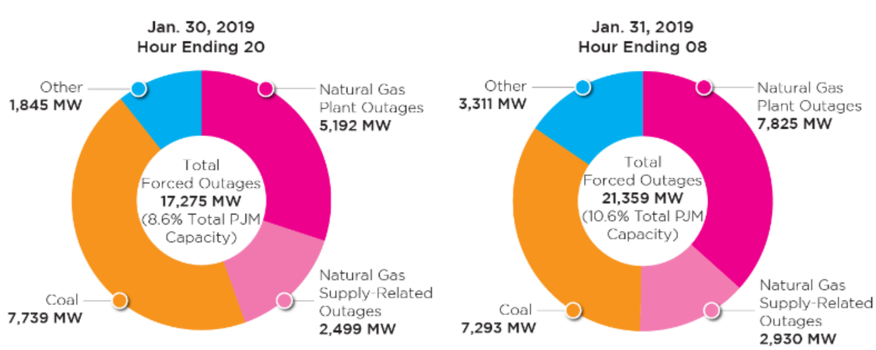
As these outages were taking place, real-time imports needed to meet high loads and counter outages increased by 3,000 and 2,000 MW on the 14th and 15th, respectively.[18] CAISO, however, notes it could have imported even more capacity if it had not had to derate the California Oregon Intertie (COI) prior to the event due to a damaged, upstream transmission line in the Pacific Northwest. CAISO stated, "...more energy was available in the north than could be physically delivered, and the total import level was less than the amount the CAISO typically receives."[19] Just as CAISO acknowledges more interregional transmission would have allowed capacity imports to reduce or eliminate the need for outages, all regions would similarly benefit from increased interregional transmission during extreme weather events.

The ability to move power between the existing interconnections is limited by the relatively small size of Back-to-Back (B2B) HVDC ties which are aging and in most cases approaching their end-of-life. The aggregate nameplate capacity of the B2B HVDC ties between the eastern and western grids in North America is only 1,320 MW and in most cases is limited by the capability of the equipment in the B2B HVDC tie substations and not the capacity of the adjacent AC systems. During the most recent blackouts in California, significant resources, which were primarily wind, were available in SPP but were not deliverable into the western grid due to the lack of capacity on the critical interface between the eastern and western interconnections.

c. Polar Vortex (January 2019)

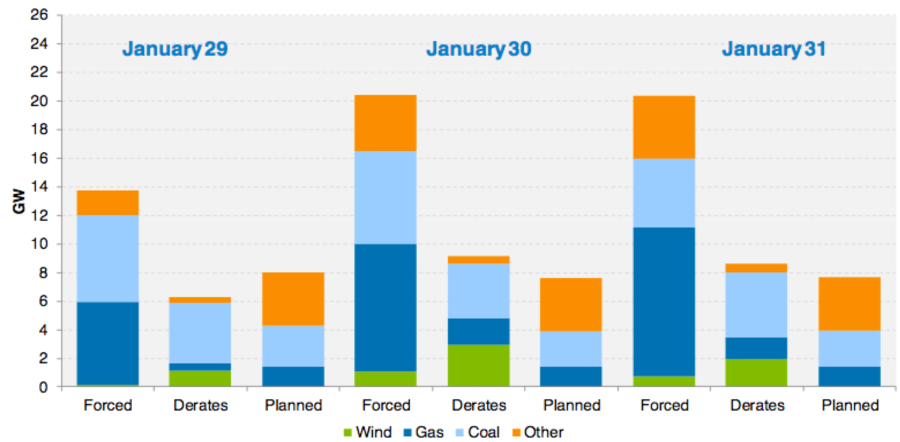
A polar vortex affecting PJM and MISO during the week of January 28, 2019 caused both RTOs to experience higher than normal levels of unplanned outages. Ex post analyses show generating units of all fuel types were impacted by forced outages. Between January 30th and 31st, PJM and MSO experienced forced outages averaging 19,317 MW and 20,500 MW, respectively. Figure 5 below depicts forced outages by fuel type in PJM from January 30th through 31st, and Figure 6 shows the total of forced outages, planned outages and derates in MISO from January 29th through 31st:

Figure 5: Forced outages in PJM during the 2019 polar vortex (January 30-31)[20]



[18] *Ibid*., at 49.
[19] *Ibid*., at 48.
[20] PJM, *Cold Weather Operations Summary January 28-31, 2019*, at 4, 2019.

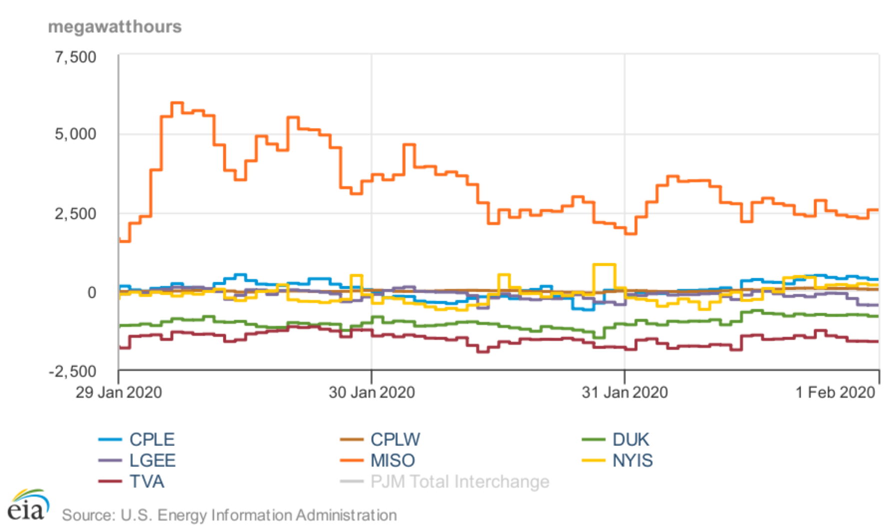
Figure 6: Generation outages and derates in MISO north/central during the 2019 polar vortex (January 29-31)[21]



During the extreme cold weather event, PJM was able to import a combined 3,500 MW from TVA, Duke Energy Carolinas, Duke Energy Progress East and West, Louisville Gas and Electric and Kentucky Utilities Company, and NYISO. At the same time, PJM was able to export over 5,000 MW to MISO on the 29th, at least partially due to higher than average wind output.

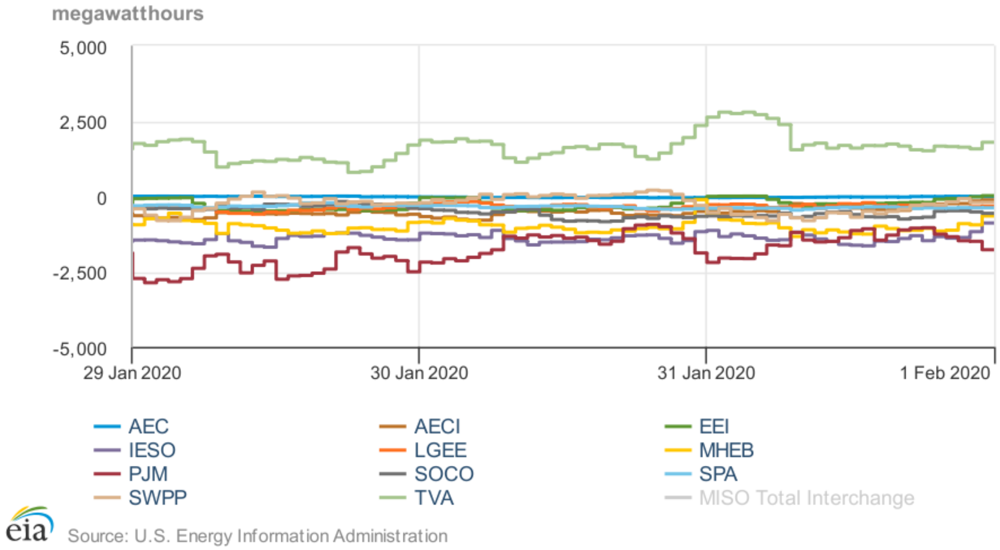
A look at MISO's import and exports during the polar vortex tells a similar story. On the 29th, MISO was able to import 7,500 MW from neighboring balancing authorities and RTOs, while exporting around 2,000 MW to TVA over the same time frame. Figures 7 and 8 below show the breakdown of imports and exports to and from PJM and MISO during the Polar Vortex.

Figure 7: PJM Interconnection, LLC (PJM) electricity interchange with neighboring balancing authorities 1/29/2019-1/30/2019, Eastern Time



[21] MISO, *MISO 2018-2019 Winter Assessment Report: Market and Operations Analytics*, at 20, April 2019.

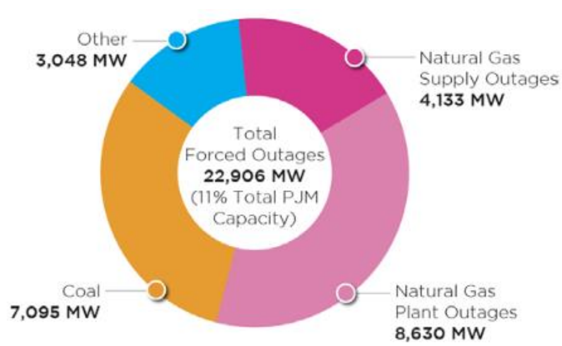
Figure 8: Midcontinent Independent System Operator, Inc. (MISO) electricity interchange with neighboring balancing authorities 1/29/2019-1/30/2019, Eastern Time



d. Bomb Cyclone (2017-2018)

The Northeast experienced a prolonged cold spell as well as a rapid plunge in barometric pressure, known as a "Bomb Cyclone," between December 26th and January 7th, which brought heavy snow and ice to the region. The weather event, which caused the coldest twelve-day stretch in New England since 1980 and three of PJM's top 10 winter peak demand days of all time, spared no resource when it came to unplanned outages. PJM found that total forced outages on the morning of January 6th totaled 22,906 MW, with most outages affecting natural gas and coal units:

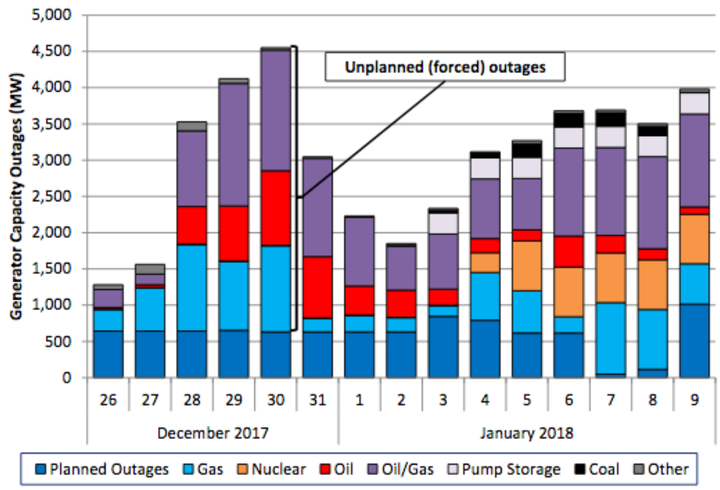
Figure 9: Forced outages in PJM during 2017/2018 bomb cyclone (January 6th)[22]



[22] Ott, *Examining the Performance of the Electric Power Systems Under Certain Weather Conditions*, Testimony of Andrew L. Ott, President & CEO PJM Interconnection, L.L.C. before the United States Senate Committee on Energy and Natural Resources, at 5, January 23, 2018.

Similarly, ISO New England found a variety of resource-types were affected by forced outages over the course of the event:

Figure 10: Average generation out of service in ISO New England by fuel type (December 26-January 9)[23]

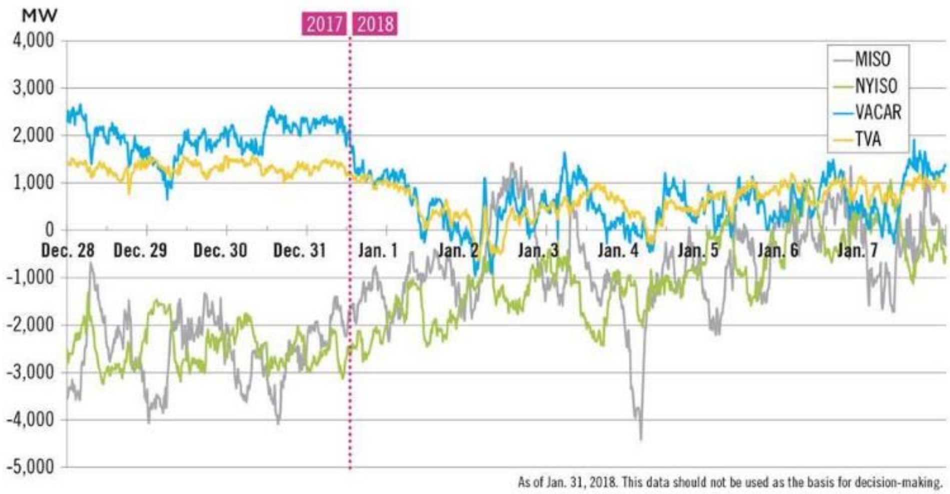


ISO New England notes in their ex post analysis that although outages peaked on December 30 at approximately 4,500 MW, consisting of predominantly oil and gas units, outages increased days later after a nuclear unit was forced out of service due to a weather-related transmission line trip.

When asked about interregional transmission during the US Senate Committee on Energy and Natural Resources hearing on the performance of the of the northeast power grid during bomb cyclone, PJM President and CEO Andrew Ott stated power was able to flow from MISO to PJM for a number of hours during the cold snap. The following graph shared in the testimony also shows NYISO was able to export approximately 2-3 GW to PJM during the first few days of the cold snap:

[23] ISO New England Internal Market Monitor, *Winter 2018 Quarterly Markets Report*, at 35, May 2, 2018.

Figure 11: PJM interchange, Dec. 28 2017 to Jan. 7, 2018[24]



e. Browns Ferry Nuclear Plant Derate Due to Extreme Heat (2010)

Much like coal-fired power plants, nuclear facilities require large quantities of water for cooling operations. Extreme weather can indirectly impact nuclear power plant operations due to cooling water intake disruptions. In 2010, a prolonged spell of hot weather forced the Browns Ferry 3.8 GW nuclear power plant in Alabama to operate at 50% of its maximum output, as surrounding river water was too warm for the plant to draw in to cool the plant's reactors.[25]

Extreme heat can cause intake and discharge water temperatures to reach levels unsuitable for cooling operations (and water quality standards in the case of discharge water), and drought conditions brought on by extreme heat can lead to a lack of cooling water. In each case, power generators can be required to curtail power generation or shut down completely. Such events are not rare occurrences. One NREL report documenting thermal generator outage and curtailment events between 2000 and 2015 found there were 25 incidents in which nuclear facilities had to curtail output or shut down operations because intake water was too warm, discharge water was too warm, both intake and discharge water too was warm, or there was a lack of intake water.[26] It's likely that these incidents will continue in both frequency and intensity as 61% of nuclear capacity in the lower 48 states is expected to face medium-high to extremely high water stress by the year 2030.[27]

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[24] *See* Questions for the Record Submitted to Mr. Andrew Ott, U.S. Senate Committee on Energy and Natural Resources, January 23, 2018 Hearing: The Performance of the Electric Power System in the Northeast and mid-Atlantic during recent Winter Weather Events, including the Bomb Cyclone at 10, 2019.

[25] Climate Central, "Heat and Drought Pose Risks for Nuclear Power Plants," July 18, 2012.

[26] McCall, Macknick, and Hillman, *Water-Related Power Plant Curtailments: An Overview of Incidents and Contributing Factors*, at 8, December 2016.

[27] Whieldon and Kuykendall, "Climate Change Poses Big Water Risks for Nuclear, Fossil-Fueled Plants," October 21, 2020.

III. Conclusion

The interconnectedness of our power grid is one of its greatest attributes. Interregional transmission can help keep power flowing when widespread, unplanned generation outages occur, as demonstrated by the extreme weather event examples described above. As planners, stakeholders, states, and regulators consider how to plan for the grid of the future, it should consider these common mode failures and should incorporate them into regional and interregional planning.