EPRI

Quick Insights

Extreme Cold Events, Changing Climate Threats, and Power System Infrastructure Resiliency

RESEARCH QUESTION

What is the polar vortex; how does it affect power system infrastructure; and how might these effects be mitigated in the future?

KEY POINTS

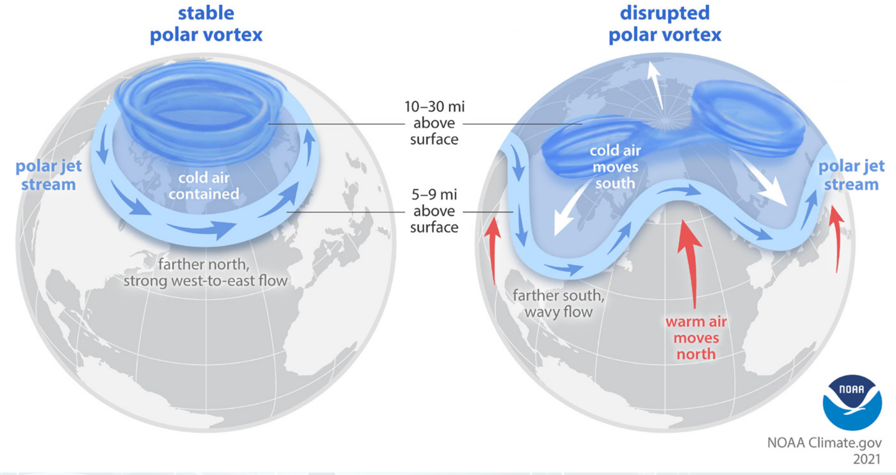
- Generation, transmission, and distribution infrastructures are impacted by extreme cold temperatures, with the potential to cause widespread, long-duration outages that negatively affect consumers and businesses.
- The relationship between climate change and changing frequency and intensity of extreme cold events (ECEs) is not clear.
- Weatherization, cold-weather vulnerability assessments, and resiliency planning and investments will be necessary to mitigate widespread outages caused by future ECEs.

CONTEXT

As a result of a temporary weakening of the polar vortex, the southern United States experienced an ECE in February 2021, which renewed concerns about reliability, resiliency, and resource adequacy in the face of extreme weather events. The large societal impacts of the 2021 ECE, and the possibility of its effects having been more profound, have reenergized a broader, energy sector-wide conversation about how best to manage extreme weather and changing climate threats.

WHAT IS THE POLAR VORTEX?

The polar vortex is an atmospheric circulation in the troposphere near the North Pole. It is surrounded by the polar jet stream, a narrow band of strong westerly winds (moving west to east) that separates cold Arctic air from warmer air.[13] A stable polar vortex keeps Arctic air bottled up near the pole. However, when the Arctic is warmer than normal, the polar vortex may weaken, allowing some of the Arctic air to move equatorward.[4] This disrupted vortex may lead to a long duration period of relatively cold weather, otherwise known as an *ECE*.[1, 2]

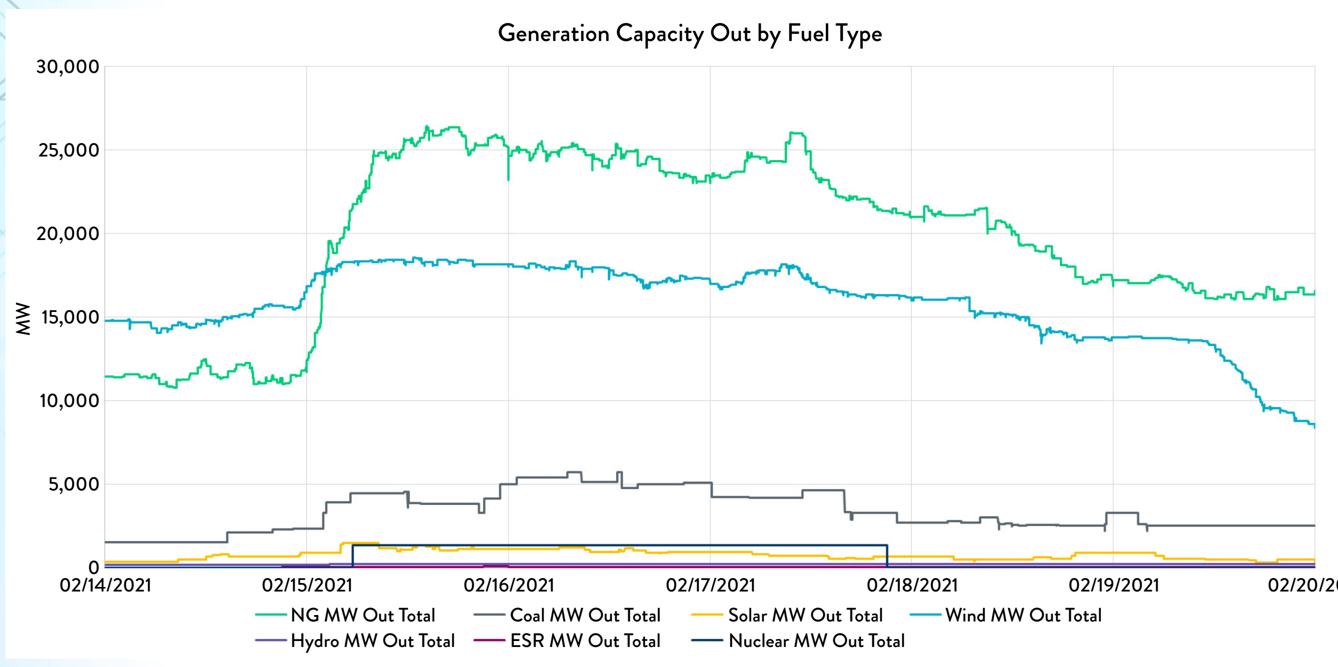


The past hundred years have seen a prominent pattern of warming, with changes in global climate effectuating much more rapid warming at the poles than at lower latitudes. In the Northern Hemisphere, this phenomenon is referred to as *Arctic amplification* (AA). That this pattern is projected to continue raises the question of whether climate change could increase the frequency or duration of ECEs; however, the existing evidence is inconclusive. AA, which is thought to be primarily driven by decreases in sea ice,[9] was linked to an increase in extreme winter weather in the midlatitudes.[4, 5] It was proposed that AA could contribute to a weakened polar vortex, leading to more persistent winter extremes.[4] More recent studies have shown this relationship between AA and ECEs to be insignificant, with ECEs largely attributed to natural climate variability.[6, 7, 10]

Variations across geography and time make it difficult for studies to consistently define ECEs. Extremely cold temperatures for Texas (for example, 10°F [-12.2°C]) may be average daily lows in Minnesota. Additionally, as climate warms in a single location, what is considered extreme cold has the potential to change. Therefore, the temperature thresholds that a study uses to define ECEs directly impacts its findings. Studies that define ECEs by absolute thresholds, or relative to the historical climate (that is, 1981–2010 Climate Normal period), project ECEs declining in frequency over the next several decades as the climate warms.[3] In contrast, studies that define temperature thresholds relative to days in future years show that ECEs, though they may be less intense, will continue to occur at a frequency similar to the present.[7]

EFFECTS OF ECEs ON POWER SYSTEM INFRASTRUCTURE

Like other climate threats and extremes (such as hurricanes, wildfires, and extreme heat), extreme cold can impact the functionality of the power system. Recent ECEs significantly impacted generation availability. An ECE in 2014 caused 19,500 MW of capacity to go offline across the Midwest, South Central, and East Coast regions of the United States. Over 17,700 MW of that lost capacity was the result of frozen equipment.[24] A 2011 ECE in Texas lasted approximately three days and resulted in 14,702 MW of the Electric Reliability Council of Texas (ERCOT)'s generation capacity being forced offline, compared to the 2021 ECE, which lasted approximately eight days and resulted in total outages of 52,277 MW of generating capacity.[31]



ERCOT report of generation capacity outage by type during the 2021 ECE[31]

Extreme cold can also impact distribution and transmission assets. Principal impacts on generation, distribution, and transmission assets are summarized as follows:

Generation Assets

Coal

- For thermal plants without enclosed heated powerhouses, instrumentation lines are necessary to maintain critical flows and pressures for the safe operation of the steam cycle. These power plants are susceptible to trips if the line freezes and readings are impacted. (Northern plants tend to include enclosed heat powerhouses for this reason.)
- Thermal power plants without enclosed heated powerhouses contain miles of tubing and piping, which can freeze if they are not online and hot when temperatures dip below 32°F (0°C), preventing restart until warmer weather occurs.
- Moisture in coal piles can freeze, making the coal more difficult to use.
- Wet coal can also reduce electric output per ton of coal and may cause issues with feeding coal to the unit.

2011 ECE

Texas coal units tripped offline, because of frozen sensing lines.

2014 ECE

22% of PJM Interconnection's total generation was offline, because of fossil generator outages.[26]

2011 ECE

The El Paso to New Mexico Gas Company delivery pipeline pressure dropped, causing outages.

Some power outages were related to natural gas supply interruptions.

The Tenaska Kiamichi Generating Station experienced frozen valves, which tripped the generator.[25]

2014 ECE

PJM Interconnection experienced a supply shortage, frozen pipelines,[27] and gelled fuel oil in filters as a result of the cold.[24]

2021 ECE

There was a lack of fuel supply and transportation ability of natural gas in the Southern Power Pool (SPP), causing outages.[28]

Natural gas generation accounted for almost 50% of outages in ERCOT territory, with an 84,000-MW reduction in total.[35]

Natural Gas

- Natural gas turbines can generate more power in cold weather than in heat. As temperature decreases, the density of air increases and a higher mass of air flows through the turbine.
- However, natural gas supply wells and transportation infrastructure can freeze as a result of moisture, especially in early stages in the gas supply, which impacts the ability of fuel to reach gas-fired power plants.
- Natural gas plants are susceptible to frazil ice buildup.
- Natural gas plants can be starved of fuel if electricity supporting the pipelines (for example, compressor stations) is shut off to help manage insufficient electricity supply.
- Some gas plants are built with backup fuel oil supplies. Switching to these supplies during cold weather can be problematic, and fuel oil supplies must be heated to ensure good fuel flow.

Nuclear

- Nuclear power plant (NPP) cooling water intakes can be impacted by frazil ice.
- Unprotected tanks and lines at nuclear units are vulnerable to freezing in extreme cold, which can have a variety of impacts on operation of the plant, up to and including the plant tripping offline.
- NPPs with turbine buildings open to the environment are more vulnerable to ECEs than those with closed turbine buildings.

2019 ECE

Public Service Enterprise Group's (PSEG) New Jersey nuclear plant tripped as a result of frazil ice buildup.[29]

2021 ECE

Instrument lines froze and caused nuclear reactors in Texas to trip offline.

2014 ECE

Wind turbines in the PJM Interconnection service territory hit their minimum operating temperatures, experienced stress from extended run times, and experienced icing.[27]

2021 ECE

12 out of 25 GW of wind power capacity in Texas went offline because of freezing.[30]

Wind

- Increased air density in cold weather can result in increased wind turbine productivity.
- Wind turbines automatically shut down if the temperature falls below operational specifications, which range from -10°C to -30°C, depending on the cold-weather package that is installed.
- Ice buildup on wind turbine blades can cause reduced output or shut down if the buildup is severe.
- The means of preventing this ice buildup typically are not cost-effective under normal operating conditions.[18]

Solar

- Solar photovoltaic (PV) modules become more efficient at converting sunlight to electricity as temperature decreases, primarily through increased operating voltage.
- Inverters are designed to function within a fixed voltage range. A sunny and extremely cold day can cause PV module voltage to exceed the inverter rating, which triggers the inverter to shut off to avoid potential damage.[18]
- Snow on PV modules can have an outsized impact on potential power production, depending on module technology and where the snow accumulates. Newer bifacial PV modules can more readily absorb light reflected from white snow, causing the module to more quickly warm and shed frontside snow.[33]

Hydro

- Extreme cold can reduce efficiency, reducing power production.
- Surface ice and frazil ice can impact unit intake.
- Mist ice can build up on spill gates, causing the gates to seize and cease operation.
- Limit switches may function at a lower level in freezing rain and wind.[18]

Transmission and Distribution Assets

Transformers

- The insulating fluid can increase in viscosity during a cold-weather outage, inhibiting heat transfer capability after restoration.
- Picking up cold load during an outage may overload transformers because of the possible surge in demand after the outage.
- For transformers with high moisture, low oil temperatures could result in moisture condensation on insulation surfaces resulting in possible flashover.
- Icing on bushings is an issue that could be further exacerbated by contamination or freezing of salt spray on the bushings.
- Monitoring and protection devices on the transformer may become impaired during cold weather.

Structures

- Ice buildup coupled with increased wind speeds can cause physical damage to transmission and distribution poles and lines.
- Ice and snow buildup on insulators can result in flashovers, especially on contaminated units, as ice starts to melt, causing individual and cascading line failures.
- Proximity to trees plays a large role in the degree of ECE effects on transmission and distribution poles and lines.
- Decreasing conductor temperatures can cause power line spans to contract, affecting short, low sag spans in particular.

2011 ECE

Outages in PNM Resources' service territory were caused by transmission trips.[25]

Conductors

- Areas that are generally considered too warm for conductor icing may be affected during ECEs.
- Radial ice buildup increases the weight on conductors, which can cause them to fail, or place strain on midspan joints and dead ends.
- Sudden shedding of ice loads creates shock loads capable of causing phase-to-phase flashovers, stresses on insulators, or structural failure.
- Cold and windy conditions, characteristic of polar vortices, may cause buildup of thin icing layers on conductors, resulting in conductor galloping (high-amplitude, low-frequency movement) that can cause faults if lines get close to each other or other damage.

Disconnect Switches

- Line icing can result in switch malfunctions.[21]

Circuit Breakers

- Cold weather can cause SF_6 to liquefy, causing circuit breakers to lock out until the gas density recovers.

2011 ECE

Low temperatures in ERCOT's service territory caused the grease in a breaker to become cold and tripped six units offline.[25]

Containerized Bulk Energy Storage Batteries

- Space heating is required to remain in operational range.[21]

Distribution Automation Equipment

- Batteries in recloser control cabinets are known to fail or report as failed.
- Sensor measurement accuracy can be affected by low temperatures.
- Thermal cycling can lead to cracking of epoxy housing.

Response and Adaptation Strategies

The preceding impacts are well understood throughout the electricity sector. The challenge is incorporating this knowledge into preparedness and resiliency planning while maintaining affordability. As demonstrated previously, ECEs can heavily impact power system infrastructure. The Electric Power Research Institute (EPRI) and the Federal Energy Regulatory Commission (FERC) have released the following operational recommendations to minimize these impacts:[32]

FERC Recommendations

- Inspect and maintain heat tracing and thermal insulation.
- Make use of wind breaks and enclosures.
- Maintain stockpile of winterization supplies.
- Conduct seasonal planned maintenance tasks in advance of known severe cold-weather periods.

EPRI Recommendations

- Conduct routine cold-weather vulnerability assessment.
- Determine plant operating temperature lower limits.
- Implement plans for preventing or removing frazil ice blockages.

Historical probabilities of the frequency, intensity, and duration of extreme events may be unreliable for future predictions, and, as such, resiliency planning and investment decision processes must evolve.[22] In addition to preparation for extreme events, weatherization of power system infrastructure is expected to play a crucial part in maintaining grid reliability. Future technologies are likewise expected to prioritize climate-resilient design features. Increasing frequency and duration of many climate events will affect resource adequacy assessments and the way energy resiliency is valued.[23]

RELATED EPRI WORK

EPRI is pursuing an institute-wide resiliency initiative that will complement and drive forward existing research in supply resiliency, climate resiliency, and transmission and distribution resiliency. Resources are as follows:

Supply Resiliency Resources

- Supply Resilience: Generation Hardening, Fuel Supply Assurance, and Generation Adaptation
- Exploring the Impacts of Extreme Events, Natural Gas Fuel and Other Contingencies on Resource Adequacy

Climate Resiliency Resources

- Temperature Impacts on Electricity Demand: US-REGEN Load Projections for Climate Resilience

Transmission and Distribution Resiliency Resources

- Transmission and Distribution Resiliency: What's Going on, and What is EPRI Doing to Help?
- Assessing Transmission Resilience to Future Climate Risk and HILF Events
- Distribution Grid Resiliency: Prioritization of Options
- Improving Grid Safety and Resilience During Extreme Weather Events and Wildfires

Resilience Planning, Valuation, and Metrics

- Identifying the Gaps and Challenges of Resilience Valuation
- Incubatenergy Labs 2020 Pilot Project Report: RUNWITHIT Synthetics — Synthetic Environments for Resilience Planning
- Technical Assessment of Resiliency Metrics and Analytical Frameworks
- Power System Supply Resilience: The Need for Definitions and Metrics in Decision-Making

Interest Groups and Other Collaborative Efforts

- Value of Resilience Interest Group
- Exploring Climate Impacts in Utility Operations and Planning Interest Group

DEFINITIONS

Compressor station. Any combination of facilities that supply the energy to move gas in transmission or distribution lines or into storage by increasing the pressure.[37]

Frazil ice. Soft or amorphous ice formed by the accumulation of ice crystals in water that is too turbulent to freeze solid; these small crystals have ineffective buoyance, causing them to sink under the surface where they can interfere with water intakes.[38, 39]

Instrumentation line. Small-diameter tubing connecting the process to an instrument such as a level or pressure transmitter.

Recloser control cabinet. A cabinet separate from the recloser that allows for manual changes of operational settings.[40]

Sensing line. A protective device installed between the pressure sensor and steam source to ensure that proper cooling occurs, thereby protecting the sensor.[36]

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CONTACT INFORMATION

Principal Investigators:
Heidi Scarth, Engineer/Scientist I
hscarth@epri.com, 202.440.0693

Erik Smith, Engineer/Scientist II
esmith@epri.com, 202.293.6188

Delavane Diaz, Principal Project Manager
ddiaz@epri.com, 650.319.5244

For inquiries regarding the technical content of this brief or for general inquiries about EPRI's Quick Insight Briefs, please send an email to QuickInsights@epri.com.

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA • 800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com