

Based on the problem definition and key insights from the NERC report analysis, several recommendations can be made to improve the resilience of the U.S. power grid:

**1. Infrastructure Upgrades:** Since aging infrastructure is a major contributor to the rise in power outages, investing in modernization and reinforcement of grid components is crucial. This includes replacing outdated equipment and implementing smart grid technologies for better outage detection and response.

**2. Weather Resilience Planning:** As weather-related events are the leading cause of outages,

- Power companies should enhance their preparedness for extreme weather by reinforcing vulnerable areas, particularly in regions with high weather variability such as WECC and SERC. Investment in weather-proofing infrastructure, like underground cables and storm-resistant structures, can help mitigate damage.
- **Vegetation Management:** Implement programs to trim trees and manage vegetation near power lines to reduce the risk of outages caused by falling branches.
- **Emergency Response Training:** Ensure that utility crews are trained and prepared for rapid response during severe weather events.
- **Smart Sensors and Automated Systems:** Deploy smart grid technology to detect outages quickly and reroute power automatically to minimize disruption.
- **Advanced Weather Monitoring Systems:** Invest in real-time weather tracking and forecasting systems to anticipate severe weather events and their potential impact on the grid.
- **Partnerships with Weather Services:** Collaborate with meteorological agencies to improve forecasting accuracy and receive timely alerts about severe weather.

**3.Regional Response Strategies:** With certain regions, like WECC and RF, showing higher susceptibility to outages, localized response and resilience plans should be developed. Regional collaboration among energy providers can improve resource allocation, particularly during extreme weather or technical disruptions.

**4.Backup Power Solutions:** Given that long outages exceeding 8 hours are common, implementing more reliable backup power systems for critical infrastructure (hospitals, emergency services) and residential areas is essential. Renewable energy sources such as solar with battery storage can also provide resilient, decentralized energy solutions.

**5.Improving Restoration Times:** The data reveals significant variation in restoration times depending on the cause of the outage. Power companies should enhance their response capabilities through advanced monitoring systems, better-trained crews, and predictive maintenance using AI. This will reduce the recovery time for both small and large-scale events.

**6.Cybersecurity Strengthening:** Since cyber events have caused significant outages,

- Strengthening cybersecurity measures is essential. This includes protecting grid infrastructure from attacks and ensuring rapid response protocols are in place to address cyber threats and implementing better firewalls, intrusion detection systems, and encryption.
- Using of advanced threat detection systems like machine learning-based anomaly detection can helped detecting and responding to attacks more quickly.
- Developing more robust backup and disaster recovery systems, allowing restoring services more quickly following a cyber incident.
- Increasing in cybersecurity awareness, with companies investing in employee training to avoid phishing

**7.Customer Communication and Engagement:** To minimize the impact of outages on millions of customers,

- Power providers should improve communication strategies, offering real-time updates and preparedness tips before and during outages.
- Enhancing customer engagement through mobile applications or alert systems can ensure timely restoration and better customer experience.

## **8. Energy Storage and Microgrids:**

- Developing microgrids and increasing energy storage capacity can help in managing demand fluctuations and providing backup during outages, especially in regions with high demand loss like SERC and WECC. Decentralized power generation can provide continuous service in isolated outages.
- Maintain optimal fuel inventory levels and use predictive analytics to anticipate demand surges, ensuring adequate supply during peak periods

## **9- Fuel Supply Issues:** Strategies that must be implemented to reduce reported outages

- Invest in alternative energy sources (e.g., renewables, biofuels) to decrease reliance on a single type of fuel.
- Maintain optimal fuel inventory levels and use predictive analytics to anticipate demand surges, ensuring adequate supply during peak periods.
- Increase storage capacity for fuel to buffer against supply disruptions and fluctuations in demand.
- Implement real-time monitoring systems to track fuel supplies and identify potential disruptions early.
- Collaborate with industry stakeholders to share best practices and resources for managing fuel supply issues

These recommendations, when implemented, could significantly reduce the frequency and duration of outages, improve restoration times, and increase overall grid resilience.

**Daily Trends:** Outages were most frequent in the afternoon and morning with total **61.47%** of total events.

**several measures can be taken to mitigate these occurrences and reduce their impact:**

- Implementing load-shedding strategies or demand response programs can reduce stress on the grid during these hours.
- Utilize load balancing techniques to distribute the demand more evenly throughout the day. Shifting non-critical loads to off-peak times could reduce the frequency of overloads leading to outages