GRID RELIABILITY IN THE CLEAN ENERGY TRANSITION

Key Takeaways and Policy Recommendations

February 2025

ENERGY INNOVATION
POLICY & TECHNOLOGY LLC

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MANAGING GRID RELIABILITY IN A CHANGING WORLD

KEY TAKEAWAYS

- Abundant, reliable, and affordable electricity is central to economic prosperity, energy security, public health and safety, and comfort.
- In the U.S. and around the world, electric grids are undergoing transitions driven by a myriad of factors, including rapid load growth, policies and regulations, consumer demand for carbon-free energy, favorable economics for clean energy technologies, retiring capacity, climate change, and extreme weather.
    - Today's challenges require new modes of thinking, planning, and operating the grid.
- The North American Electric Reliability Corporation's (NERC) 2023-2024 summer and winter reliability assessments find that electricity supply is sufficient across the country under normal conditions, but during extreme heat and cold, several regions are at risk for supply shortfalls.
    - Load growth and the retirement of aging and expensive fossil fuel power plants are the primary causes of the reliability risk.
    - Winter reliability risks are largely due to inefficient heating, poor performance of gas-fired power plants, and fuel supply constraints. In some regions, periods of low wind or forecast uncertainty can increase risks as well.
    - Wind, solar, and battery energy storage contribute to grid reliability, but interconnection challenges and timing of additions may not fully replace retiring capacity.
- In 2023, the U.S. generated 40 percent of its electricity from carbon-free sources, with wind and solar making up 15 percent and nuclear energy, hydroelectric energy, and geothermal energy making up the remaining 25 percent.
    - The growth of clean energy resources introduces new concerns about how to plan and operate a reliable grid integrating these new technologies.

NUTS AND BOLTS OF RELIABILITY

There are three separate but interconnected components of electric reliability:

- *Resource adequacy* means having enough energy to meet demand; this is a longer-term dimension of reliability that requires extensive analysis and planning to estimate long-term demands and design and implement measures that deliver sufficient new resources to serve those demands.
    - No resource is available 100 percent of the time. Even fossil fuel plants can experience weather-dependent outages.
- *Reliable operation* (or operational reliability) refers to balancing energy supply and demand in real time to maintain frequency and voltage within safe operating limits. It is the shorter-term dimension of reliability and requires regular monitoring and control of the entire grid.
    - This is a short-term dimension of reliability that requires ongoing efforts to design and implement markets, operational rules and systems, and infrastructure to support day-to-day grid operations.
- *Resilience* is the ability of the grid to ride through extreme events, recover quickly, and support other critical systems (e.g., transportation, health care, public safety, etc.).
    - Connected to resilience is grid hardening, which refers to a myriad of technology and operational solutions that help the grid withstand major events without disruption.
- *Reliability* is a characteristic of the whole electricity system, to which individual resources contribute.
    - Every source of electricity has different characteristics that should complement each other in a balanced portfolio.
    - Maintaining a reliable grid requires valuing every resource's contribution accurately and building a generation portfolio that balances supply and demand throughout the day and year.
- When electricity supply and demand are matched, electricity flows through the grid at a constant frequency and voltage; but as supply and demand vary throughout the day, frequency and voltage can begin to fluctuate.

    - *Essential reliability services* are the contributions that operators call up from different resources to keep the frequency and voltage of the grid stable.
- A reliable electricity portfolio does not necessarily need to include "baseload" or 24/7 resources, which are plants that are expensive to build but historically cheap to operate and therefore run almost all the time.
- One of the biggest threats to grid reliability is speed: we need to be able to interconnect new generation, build transmission, and upgrade the distribution system faster to meet today's grid challenges.

RESOURCE ADEQUACY AND ENERGY STORAGE

KEY TAKEAWAYS

- In 2024, the U.S. added 56 GW of new generating capacity to the grid; wind, solar, and batteries account for 93 percent of new generating capacity, and they make up most of the new generation in queues.
    - Wind, solar, and batteries can provide essential reliability services.
    - Numerous large, sophisticated grids regularly run on a 70 percent or higher share of wind and solar for hours at a time.
- Numerous studies agree that the U.S. can technically achieve up to 90 percent clean electricity generation using today's technologies, but inadequate policies and market rules could stifle the development of resources needed for a reliable grid.
- The shift from fossil plants to clean resources is raising concerns about resource adequacy (i.e., whether there are in fact enough resources to supply energy and capacity to meet rising demand while accounting for uncertainties in load, weather, and unexpected outages).
- It is feasible to ensure resource adequacy with clean energy resources, if we can bring them online fast enough. Interconnection reform is one of the most important steps to ensuring future resource adequacy.

POLICY AND REGULATORY RECOMMENDATIONS

- State utility regulators, utilities, and grid operators should remove barriers to building new, clean resources and interconnecting them to the grid in a streamlined, cost-effective way.
- State policymakers and utilities should coordinate at the regional and interregional levels to plan and build new transmission in an expedited manner.
- State utility regulators and utilities should pursue proactive distribution system upgrades and improved planning approaches to support grid reliability on the demand side, especially in the context of new load growth and extreme weather events.

- Existing gas will be an important part of the power system for the foreseeable future, but its value will shift toward use as a capacity resource and its contributions to overall energy will decrease.
- Fossil fuel resources are subject to extreme weather and are not available 100 percent of the time. Failure to account for this is a major pitfall in current resource adequacy planning with serious implications (e.g., during Winter Storm Uri, un-winterized gas plants across the state of Texas failed simultaneously, making up 58 percent of the unplanned outages; during Winter Storm Elliott, gas plants made up 70 percent of the unexpected outages).
- Uncertainty exists around which resources will constitute the final 10-20 percent of energy in a 100 percent carbon-free grid, but that doesn't mean we should slow the deployment of other affordable resources like wind, solar, and batteries on our path to full decarbonization.
- The reliability value of each resource depends on the makeup of the rest of the grid, and a more diverse grid increases the reliability value of each individual resource.
- Resource adequacy risks are shifting as the grid changes, and reliability must be evaluated at all hours of the year (not just during times of peak demand). In general, risks will shift to later in the evenings when solar is unavailable and into the winter season.

POLICY AND REGULATORY RECOMMENDATIONS

State utility regulators, utilities, and grid operators should:

- Use an energy-only interconnection approach, when possible, which involves more limited studies and upgrades and allows resources to come online faster but requires resources to take additional curtailment risk and often cannot participate in capacity markets.
- Utilize grid-enhancing technologies and advanced conductors to quickly upgrade the capacity of existing transmission lines.
- Proactively plan and build transmission to enable reliability through retirements, instead of waiting until retirement is imminent.
- Analyze reliability risk across all hours of the year using chronological modeling and assess a diversity of portfolios against metrics like expected unserved energy and loss of load expectation that examine all hours of the year.
- Recognize that all resources have challenges in meeting reliability needs and accredit their reliability value accordingly.
- Prioritize and pursue demand-side resources and energy efficiency solutions, which in most places are cheaper than new power plants, faster to deploy, and capable of shifting or reducing energy usage during times of grid strain.
- Pursue comprehensive long-term resource planning (that includes transmission).

REAL-TIME OPERATION OF A DIVERSE PORTFOLIO

KEY TAKEAWAYS

- Electricity supply and demand must be kept in balance to maintain relatively constant frequency and voltage, which ensures stability of the power flowing through electric lines.
- Reliability services help balance supply and demand during the real-time operation of the grid, to minimize disturbances beyond a nominal amount.
- Not every resource must provide all types of reliability services; rather, the grid's portfolio must be able to respond appropriately to bring the grid back to balance and resume "normal" operating conditions. Each grid service available in the portfolio acts in a particular time frame.
- During major disturbances, the portfolio must be able to ride through the event without cascading failures and have sufficient response capabilities to maintain frequency and voltage.
- Grid operators traditionally have obtained reliability services from large thermal units and rotating machines, whose spinning mass provides inertia that contributes to grid stability. New resources behave differently from incumbent resources. Unlike rotating machine predecessors (also called synchronous resources), the response of new inverter-based resources (IBRs) is determined by software controls.
- IBRs (wind, solar, and batteries) can provide reliability services, often on an even faster and more accurate basis than thermal resources. New advanced controls allow batteries to provide

POLICY AND REGULATORY RECOMMENDATIONS

- Legislators, utilities, grid operators, and energy offices should support and trust ongoing efforts among grid experts to evaluate and achieve consensus around technical performance. States should lean on collaborative networks, such as the Energy Systems Integration Group and the U.S. Department of Energy national laboratories, to inform near-term solutions and new approaches.
- Grid operators should update energy market rules, economic incentives, interconnection requirements, and grid codes to reflect the real-world operating characteristics of various technologies, allowing and encouraging resources to "show up" with and be sufficiently compensated for grid services.
- Utilities and grid operators should:
  - Evaluate the full potential of new resources to ensure the grid of the future can provide needed services based on new and emerging technologies.
  - Accept consensus findings and adopt new approaches.
  - Ensure technology settings allow for certain characteristics to be made available and become more familiar with the dynamic capabilities of IBRs.
  - Prioritize solutions that aim to increase geographic diversity of the grid to minimize the impact of weather dependency, such as more transmission and better coordination between grid regions.

enhanced grid stability, as numerous recent reliability events have demonstrated.
- Grid services of IBRs are not as well understood by grid operators, presenting a barrier to using them to their full capabilities. The decline in inertia caused by large thermal retirements and replacement by IBRs does not necessarily pose a problem for the grid; ongoing studies are evaluating these tradeoffs and ensuring software controls are appropriately set.
- We're learning that even in the absence of most or all inertial response, IBRs can respond nearly immediately after the triggering event.

DEMAND-SIDE SOLUTIONS

KEY TAKEAWAYS

- Electricity demand is increasing after more than two decades of nearly flat load growth, largely driven by new electricity demand from data centers, onshoring manufacturing, agricultural and industrial electrification, cryptocurrency mining, and electrification.
    - Load forecasts are wide-ranging, with some utilities predicting a doubling or more over the next decade. But forecasts are extremely uncertain and subject to debate.
    - We cannot assume demand is immutable. Climate change-driven weather shifts and extreme weather are making demand less predictable.
- The electricity grid is still largely designed and operated to ramp supply-side resources to meet shifting demand, but in the face of rapid growth combined with extreme and unpredictable weather, we need to shift away from solely supply-centric approaches to ones that activate demand-side resources and flexible loads to their full potential.
- Demand-side solutions are a cost-effective, least-regrets way to manage growth in the near term, while unlocking their full potential over the long term. They are more cost-effective and faster to deploy than large power plants and transmission, and they can support prudent supply-side resource adjustments.
- Demand-side solutions encompass a wide range of technologies and applications that have the potential to moderate the growth of both electricity consumption and peak load.
    - Their decentralized nature makes them less visible and more complex to plan for and manage. They are harder to scale, which can prevent them from providing grid services.
- Electricity customers capable of reducing their impact during peak times could drastically reduce the need for new supply-side resources (thus bringing economic value to the grid and other customers). But capitalizing on this demand flexibility potential requires adequate incentives.
- Demand-response programs deployed at scale can be highly effective at managing new load growth and serving existing load while contributing to grid reliability.

- Today's demand-response programs stack up to a mere 60 GW of capacity—about 7 percent of national peak-coincident demand—and residential and commercial customer programs make up only 30 percent of that.
  - In some states, less than 1 percent of peak is met with demand-side solutions, with only a handful of states exceeding 10 percent.
- By 2030, nearly 200 GW of cost-effective load flexibility potential will exist in the U.S., which is more than triple the existing capability, and will be worth more than $15 billion annually in avoided system costs.

POLICY AND REGULATORY RECOMMENDATIONS

State policymakers, utility regulators, and utilities should:

- Increase visibility into demand-side resources for utilities and grid operators by using management systems, employing more sophisticated models and control devices, and allowing third-party aggregators to work directly with customers and utilities to administer effective demand-side programs.
- Enable secure data sharing across transmission and distribution systems to unlock the full potential of demand-side resources. This includes real-time operational data, infrastructure and load data to model how the grid will behave, and data used for planning and load forecasting.
- Support the adoption of shared models that can communicate with one another and use data in the same way.
- Improve load forecasts and grid planning approaches with an eye to unlocking the full potential of demand-side resources over the long term. New tools are emerging that can inform more granular distribution planning efforts, such as integrated distribution system plans and publicly available hosting capacity maps.
  - Require detailed distribution system plans in states that require utilities to develop integrated resource plans; those two efforts should be closely coordinated, such as ensuring common load forecast assumptions.
- Design programs and rates to work for energy customers so they are compensated fairly and empowered to participate. Economic incentives should be commensurate with any perceived or actual sacrifice and with the value they deliver to the electric system.
- Adopt utility performance incentive mechanisms to incentivize demand-side programs and put them on a level playing field with supply-side resources.
- Attract more flexible and grid-supportive loads by developing tariffs that encourage or require new load sources to respond to grid conditions and evaluating cost allocation for grid upgrades.

CLEAN FIRM ENERGY

KEY TAKEAWAYS

- Clean firm energy, or weather-independent carbon-free energy, means resources that can support a 100 percent carbon-free grid in the future. But many of these technologies are not yet commercially available at scale and are far more expensive than wind, solar, batteries, and demand-side resources.
- Clean firm power includes resources like geothermal, nuclear, gas with extremely high levels of carbon capture and sequestration, and potentially long-duration storage from battery storage or hydrogen resources.
- According to some analyses, clean firm energy could constitute up 10-20 percent of total energy production in a decarbonized grid in the least-cost modeling scenarios. But clean firm energy is not a silver bullet for decarbonizing the grid.
- Since we are far from 100 percent clean, we have time for technologies and grid operations to evolve.
- Rather than dwelling on uncertainty about what the last 10-20 percent of a clean grid looks like and what that perfect clean firm resource is, we should build as much clean energy as we can today.
- The biggest myth about clean firm energy is that there is a choice to be made between the combination of wind, solar, and batteries, and clean firm energy. The most affordable system will be a combination of all of these because they each play a different role on the grid. Clean firm energy will best function as a smaller part of a portfolio of resources.
- Clean firm energy resources need ongoing support from federal research laboratories as well as state policymakers, regulators, and utilities to support deployment for future grid decarbonization.

POLICY AND REGULATORY RECOMMENDATIONS

State utility regulators should:

- Ground-truth utility proposals on clean firm energy.
- Open investigatory dockets to learn more about clean firm energy resources.
- Request information from vendors on technology status and cost.
- Allow utilities to explore small-scale procurement activities to gain experience with initial commercial deployments.
- Allow partnerships between utilities and large customers that want to take on the risk and cost of early deployment of clean firm technologies without exposing customers to undue costs.
- Independently evaluate the pathways toward commercialization.