ELECTRICITY ADVISORY COMMITTEE

Bridging the Visibility Gap: Advancing Grid Resiliency and National Security With Last-Mile Digitization and Enhanced Distribution-Level Tools

Electricity Advisory Committee Recommendations for the U.S. Department of Energy June 05, 2025

Executive Summary

The U.S. electric grid has made significant advancements in transmission, substations, and smart metering, yet a critical visibility and controllability gap persists at the distribution level. This gap hinders efforts to enhance grid resiliency, operations, and affordability. The Department of Energy (DOE), as a leader in national energy security, must prioritize last-mile digitization, analytics and grid-edge management to address this issue. By investing in real-time monitoring and grid-edge solutions, standardizing modernization efforts, and focusing on rural and critical infrastructure areas, the DOE can drive industry-wide action to fortify the grid.

The Grid Modernization Journey and Remaining Challenges

While grid modernization has strengthened transmission and substations, significant gaps persist in distribution networks, particularly in rural and underserved areas. Distribution networks—particularly in rural and underserved areas—remain predominantly analog and lack real-time monitoring capabilities. At the same time, distribution-level customers are increasingly installing behind-the-meter, inverter-connected devices such as back-up generators, solar generation and batteries that change distribution and bulk power system dynamics, and automation and end-use devices that both affect and respond to changes in grid frequency and voltage. Few utilities have visibility into the impacts of these diverse grid-edge measures on distribution system capabilities or on bulk power system dynamic behavior.

This absence of visibility creates additional risks at every level of the nation's electric system. It contributes to operational gaps and surprises, extended outages, increased operational costs, and failure to anticipate and address potential issues proactively. While major industry players have digitized significant parts of the grid, the last mile remains weak.

Digitization alone won't solve these problems. Utilities already collect a significant amount of grid data that they don't use effectively, for reasons that include lack of incentives, poor data quality, poor data communications, inadequate monitoring and analytical tools, or lack of ability to translate insights into actionable tools to identify and implement real-time grid operations and protection measures. A solid distribution modernization effort must address the span from digitization and data creation through to action, in the control center and at the grid edge. DOE must spearhead efforts to bridge this gap and complete the modernization journey at the distribution level, including new modes of operation such as microgrids and distribution grids supported by local resources. Better understanding of these emerging needs and capabilities which will enable better insight and protection at every level of the grid.

National Security and Economic Implications

A resilient and modernized grid is essential for national security. Critical infrastructure—such as hospitals, emergency response centers, and telecommunications hubs—relies on uninterrupted power to maintain essential services. However, natural disasters, cyberattacks, human errors and physical threats increasingly endanger these vital services. Addressing the visibility and local control gap in the distribution grid would provide real-time situational awareness and enable creation of tools to better manage the grid. This would enable utilities to foresee and mitigate risks before they develop into widespread disruptions. Additionally, this information could be crucial for states to integrate into the State Energy Security Plans, which include sections on risk assessment and risk mitigation.

The economic impact of grid inefficiencies is significant. Outages cost the U.S. economy billions of dollars annually in lost productivity and emergency response efforts. The most high-risk areas—rural communities, critical public facilities, and industrial zones—bear the brunt of these failures. Investing in last-mile digitization and modernization measures and tools to analyze and act upon these data would enhance economic stability, reduce costs for utilities and consumers, and facilitate the transition to a cleaner, more resilient energy system.

The Double-Edged Sword of Grid Digitization

As utilities digitize their grid infrastructure, they must navigate several interconnected threats, particularly from hostile state actors.

1. Cybersecurity vulnerabilities arising from increased connectivity and automation include Living off the Land (LotL) attacks, IoT and Edge Device vulnerabilities, and AI-driven attacks.
2. Vulnerability of grid-edge inverters and power electronics devices, all of which are intelligent, cloud connected power electronic devices (many of which are made in China or other overseas locations), that can also conduct coordinated attacks where the sum total of involved devices can be a significant part of the grid. In these instances, the coordination can be based on grid physics, and not cyber principles, making traditional cyber principles difficult to apply.
3. Supply chain exploitation occurs when adversaries compromise hardware, software, or firmware prior to deployment. This threat also includes software supply chain attacks, such as the SolarWinds breach, and overreliance on unvetted vendors who embed backdoors in their products, like the dependency on foreign transformer manufacturers due to supply shortages.
4. Complex data and analytical systems can fail for many reasons, including human error, communications failures, and failures to maintain and update code and equipment.
5. Communications system vulnerabilities

Mitigation could include:

- Zero trust architecture (ability to operate the ‘real-time-must-run’ grid in suboptimal mode with no communications until the cyber threat is resolved)
- AI-powered threat detection and locally initiated isolation of compromised circuits using enhanced ‘smart meters’
- Resilient operational technology networks
- Vendor risk management
- Tamper-resistant hardware
- Domestic and allied-nation sourcing
- Operational and management guidelines and automated self-testing for system owners/users
- Enhancing collaboration among state and federal governments, utilities, and technology providers to exchange information on emerging threats.

Supporting Evidence

The DOE’s previous grid modernization initiatives and AI-driven predictive maintenance programs showcase the benefits of enhanced visibility. A new requirement coming from the increased penetration of inverter-based resources on the grid is the need to ensure the grid is under operator’s control. Data from utilities show that real-time monitoring decreases outage duration, extends asset

life cycles, and bolsters cybersecurity. Reports from NERC, IEEE, and other industry leaders underscore how bridging the last-mile visibility gap reduces costs and enhances service reliability.

The Edison Electric Institute (EEI) reports that the frequency of outages has risen by 16% in recent years, while their duration has increased by 20%. Furthermore, according to the 2021 Infrastructure Report Card, 92% of all outages occur in the distribution grid, which further underscores the urgency of last-mile digitization. The Lawrence Berkeley National Lab found that as of 2023, 90% of outages occur on the distribution system. And of all major U.S. power outages reported from 2000 through 2023, 80% were due to weather events. New data from grid operators across the globe is also showing that systems with a high penetration of inverter based resources tend to have more stability problems, with frequent outages (such as the recent outage in Spain). Traditional measurement tools, such as Phasor Measurement Units or PMUs, do not have the fidelity to measure the higher bandwidth disturbances that are now being seen. This also represents a gap in current utility monitoring and visibility.

Recommendations to the DOE

1. Last-Mile Digitization

- Support the deployment of diverse interoperable sensors, edge computing platforms, and advanced analytics for real-time situational awareness at the distribution level. These need to address the condition and status of distribution equipment and inventory, monitor and interpret the impacts of distribution-connected equipment and schemes such as customer back-up facilities, large concentrations of EV charging and batteries, and the operation of demand management schemes.
- Digitize poles, transformers, and substations to enhance operational awareness. Utilize the last utility device at the grid-edge, i.e. the Smart Meter, as a tool to monitor, validate and control behind the meter devices, to ensure that they are complying with grid codes, are not participating in a coordinated attack on the grid, and can locally act to isolate the behind the meter resources in case a problem is detected (even when the communications systems are down or compromised).
- Develop guidelines and tools to improve data collection and transport from the distribution system and grid edge to control rooms.
- Develop analytics to ensure that coordinated attacks from behind the meter can be detected.
- Develop guidelines for behind the meter inverter-based resources to ensure that they do not interfere with grid operation.
- Develop tools and guidelines for utilities to evaluate and improve distribution data quality and communications.
- Develop analytical tools to process collected data and extract insight and constructive actions to protect the grid and the devices and facilities connected to it, with insight about where (at the grid edge or in the control room) it would be most efficient and effective to process and act upon grid data to address various issues and risks.
- Evaluate distribution system modernization hardware and schemes (including distributed storage and generation and “self-healing” technologies) to determine which past, current and emerging measures offer the highest benefit for improving grid operational efficiency and preventing and fixing distribution-level outages
- Expand the use of AI and machine learning to enable predictive diagnostics and automate condition-based maintenance strategies for utility distribution assets, reducing downtime and operational risk.

2. Standardization and Stakeholder Collaboration

- As these tools and insights develop, promote the development and adoption of consistent technical standards and testing for last-mile grid modernization to improve efficiency and interoperability across utilities.
- Convene consumer- and investor-owned utilities, technology providers, State Energy Offices, and Public Utility Commissions to align on interoperability, best practices, and implementation pathways.
- Encourage public-private partnerships to accelerate deployment and innovation.
- Engage and coordinate electric industry action on distribution system digitization with major customer segments and actors (distributed generation and solar vendors and developers, Virtual Power Plant developers, retail electric providers and load-serving entities, demand response providers, electric vehicle manufacturers and charging companies) to assure that initiatives on distribution digitization complement and enhance those activities.

3. Prioritizing Rural and High-Risk Areas

- Prioritize funding and technical assistance for digital infrastructure deployment, including high-speed communications, in high-risk and underserved areas where outage frequency and restoration times are greatest.
- Ensure critical infrastructure—such as hospitals, water systems, and emergency response facilities—has enhanced power resiliency.
- Provide funding and incentives for utilities to upgrade last-mile infrastructure in high-risk areas.

Supporting Evidence and Case Studies

The DOE's previous grid modernization initiatives and AI-driven predictive maintenance programs showcase the benefits of enhanced visibility. Digitization and monitoring will yield grid and equipment information that motivates action to improve critical infrastructure resilience. Data from major utilities show that real-time monitoring decreases outage duration, extends asset life cycles, and bolsters cybersecurity. Reports from NERC, IEEE, and other industry leaders underscore how bridging the last-mile visibility gap cuts operational costs and enhances service reliability.

The Edison Electric Institute (EEI) reports that the frequency of outages has risen by 16% in recent years, while their duration has increased by 20%. Furthermore, the 2021 Infrastructure Report Card, 92% of all outages occur in the distribution grid, which underscores the urgency of last-mile digitization.

Conclusion

Closing the visibility and edge-control gap in the distribution grid is the next critical step in the nation's grid modernization journey. By prioritizing last-mile digitization, standardization, and targeted investment in rural and critical infrastructure areas, the DOE can lead efforts to strengthen national security, improve affordability, and enhance overall grid reliability and resilience.

This is a pivotal opportunity for the DOE to champion an initiative that delivers measurable improvements in reliability, efficiency, and national security. The subcommittee recommends that the DOE take immediate steps to convene industry and other stakeholders and establish a roadmap for accelerating last-mile digitization.

Sources

1. Grid Modernization Initiatives

- **U.S. Department of Energy's Grid Modernization Initiative**: This initiative collaborates across the DOE to develop a modern power grid that is more resilient, reliable, and secure.

  energy.gov

- **Grid Modernization Laboratory Consortium (GMLC)**: Established as a strategic partnership between the DOE and national laboratories, the GMLC coordinates research and development efforts to support grid modernization.

  gmlc.doe.gov

2. AI in Predictive Maintenance

- **Argonne National Laboratory's Research**: Argonne scientists are utilizing artificial intelligence to proactively identify potential issues in the energy grid, enabling just-in-time maintenance and reducing operational costs.

  anl.gov

3. Economic Impacts of Grid Inefficiencies

- **U.S. Department of Energy's Investment in Grid Resilience**: The DOE announced a $2.2 billion investment to revamp the nation's power grid to protect it against growing threats from extreme weather events, aiming to enhance the electric transmission system and improve transmission of renewable power.

  reuters.com