Electricity System Operability and Reliability under Increasing Complexity: A Workshop

June 17-18, 2024

Suggested Pre-Reads

NATIONAL ACADEMIES *Sciences Engineering Medicine*

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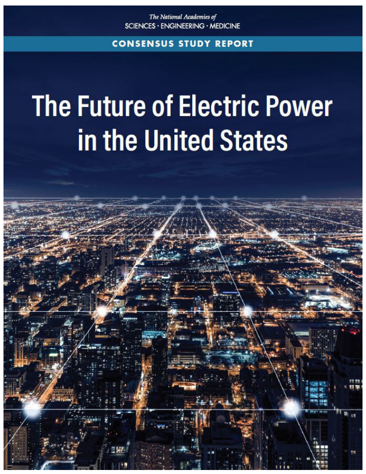
The Future of Electric Power in the United States



Electric power is essential for the lives and livelihoods of all Americans, and the need for electricity that is safe, clean, affordable, and reliable will only grow in the decades to come. At the request of Congress and the Department of Energy, the National Academies convened a committee of experts to undertake a comprehensive evaluation of the U.S. grid and how it might evolve in response to advances in new energy technologies, changes in demand, and future innovation.

The Future of Electric Power in the United States presents an extensive set of policy and funding recommendations aimed at modernizing the U.S. electric system. The report addresses technology development, operations, grid architectures, and business practices, as well as ways to make the electricity system safe, secure, sustainable, equitable, and resilient.

DRIVERS OF CHANGE

While it is difficult to anticipate what the future U.S. electric power system will look like, the committee identified a number of social, technical, and economic forces that hold the potential to bring about change in the U.S. power system.

- ***Possible large growth in future demand for electricity.*** The broadly anticipated push for deeper electrification of the buildings, transportation, and industrial sectors could lead to very different patterns and levels of electricity demand over the next few decades.
- ***Efforts to decarbonize the U.S. economy and eliminate the emission of conventional pollutants***. This will require a dramatic shift away from fossil fuel technologies to low or zero-emission sources of electricity across energy, transportation, buildings, and industrial sectors.
- ***Developments at the edge of the grid such as distributed generation, storage, microgrids, energy-management resources, and energy efficiency measures***. This is driven by the growing availability of commercial technologies such as rooftop solar energy and battery storage, as well as concerns about supply vulnerability in the face of natural or human-based disruptions.
- ***Grid stability challenges arising as a result of high penetrations of non-dispatchable sources of generation such as wind and solar***. The intermittent nature of wind and solar complicate the operation of power systems and create challenges of both insufficiency and excess. Solutions could include dispatchable and just-in-time zero-emission power generation, energy storage, and demand response technologies.

- ***A desire to reduce social inequities***. Paying for adequate energy is a heavy burden on many low-income households, and many existing fossil fuel plants are in communities that have been disproportionately impacted by negative health effects from their emissions. As the electricity system evolves, care should be taken to ensure that electricity is universally available and affordable, and that disadvantaged communities are not unfairly burdened.
- ***Concerns about the impacts of the energy transition on employment***. While the transition to a sustainable and cleaner electricity grid will mean some job losses, many traditional jobs in the electric sector will remain relevant as the grid evolves, and increases in renewables, energy efficiency, and security will be a source of new employment opportunities. Job placement and retraining for displaced workers will be needed as well as federal policy to help meet and understand future workforce challenges.
- ***The globalization of supply chains***. Many suppliers of electricity system equipment have chosen to move their manufacturing and development overseas. Plans for expanding electricity infrastructure in the U.S. need to be cognizant of this changing geopolitical environment.

MAJOR NEEDS FOR THE FUTURE U.S. ELECTRIC POWER SYSTEM

The report makes forty recommendations to meet five major needs for the future U.S. electric power system, as summarized below. For a full list of recommendations sorted by actor (Department of Energy, Congress, State Entities, and Industry), download the full report at **nap.edu/25968**.

Need #1: Improve our understanding of how the electric power system is evolving. The U.S. electric system is undergoing rapid changes due to new technologies, efforts to decarbonize, and new patterns of electricity consumption. The nation needs to invest in research to support these changes, including analytical tools to understand how the grid of the future will behave and how operators and policy makers can ensure its continued reliability and resilience. Specific recommendations call for:

- Multi-year government support for key **electricity research initiatives** such as grid modernization and technology development
- Sustained collaboration across national labs, academia, utilities, and industry to carry out **large-scale grid simulations**
- Development of **better grid architectures; updated regulations, policies, standards; and better assessments** of how technologies may affect grid architectures, based on insights gained from large-scale simulations and field experiments.

Need #2: Ensure that electricity service remains clean and sustainable, and reliable and resilient. In the coming decades, reducing carbon emissions and other environmental impacts of electricity generation will remain a major challenge. It will also be important to increase the resilience of the grid to natural disasters and targeted attacks. Meeting these challenges will require continued investment in critical power system elements such as long-distance transmission, reliability requirements for the natural-gas delivery system, and improved cybersecurity capabilities and information-sharing. Specific recommendations call for:

- A joint task force with the authority to **investigate in a timely manner why a significant physical and/or cyber disruption occurred** and identify lessons learned.
- A central entity to **oversee the reliability and security of the nation's natural gas delivery system**.

- Support across the government for the evolution, planning, and **siting of regional transmission facilities** in the United States.
- Research and development on **low-carbon technologies, storage systems, power electronics, and control technologies** to enable real-time control of the grid.
- Cybersecurity research, training, and regulations to **increase grid resilience and develop secure components**
- Mechanisms for communicating and **reporting potential security risks** to stakeholders in a timely manner as well as exercises to improve grid security.

Need #3: Improve understanding of how people use electricity and sustain the "social compact" to keep electricity affordable and equitable in the face of profound technological challenges. Changes in the grid reveal opportunities for new services and configurations of electric resources, but these changes can also have large impacts on customers and low-income communities. It is crucial to develop our understanding of how people use electricity and devise regulatory responses to evolve and strengthen social compacts to deliver electricity fairly and affordably. Specific recommendations call for:

- Regular evaluation of how new rate structures and other policies will affect **equity issues**.
- **Behavioral and social science research** needed to inform policy and technology development.
- **Funding to support vocational, professional, and academic training programs** for the current and future workforce in the electricity sector.
- **Investment in analyses to better address equitable worker transitions** across the electricity sector, including wage impacts from job displacement and retraining.

Need #4: Facilitate innovations in technology, policy, and business models relevant to the power system. Understanding how electricity consumers behave, how devices and energy services can be aggregated for supply, and how such trends affect system loads is emerging as one of most profound technological challenges and opportunities facing the future of the grid. Increasing numbers of distributed devices also motivate the need for advanced situational awareness and control at the grid edge. Technology, policy, and business models must be flexible enough to coordinate and respond to changing conditions for large-scale and local-level electricity services. Specific recommendations call for:

- Support for **social science research and policy analysis** to identify and evaluate alternate models for the retail segment of the electric system.
- **Seed grants to support innovative state programs** on new business models.
- **Expanded funding for loans, loan guarantees, and grants** to provide equivalent opportunities for investment in local utility infrastructure development for publicly owned utilities, including municipal electric utilities, cooperative utilities, and tribal utility authorities.
- Accelerated investigations into what technical and business changes are needed to **enable significant deployment of distributed energy resources and to address equity issues** related to energy access and clean energy.
- Regulatory reform to allow utilities to recover the costs of larger R&D budgets and **encourage the adoption of new technologies**.

Need #5: Accelerate innovations in technology in the face of shifting global supply chains and the influx of disruptive technologies. Many power system technologies were first developed in the U.S., but supply chains for most critical components have now moved overseas. Massive new private and public investments are needed for cutting-edge technologies on which the future grid will depend. In this, the U.S. must balance competing goals to capitalize on global innovation while ensuring U.S. control and access to critical grid technologies. Specific recommendations call for:

- **Doubled funding for basic science research** broadly related to electric power and **tripled funding for applied development and demonstration**.
- Better **regulatory tools for dealing with imported equipment** and cross-border ownership of firms producing critical equipment for the grid, as well as a program for **manufacturing critical technologies within the U.S.**
- Strategies to support **international collaborations on pre-competitive energy research** and technology development.
- Development of technologies to enable the high levels of **automation needed in the future grid**.

DOWNLOAD THE REPORT AND RELATED PUBLICATIONS AT THE NATIONAL ACADEMIES

- *The Future of Electric Power in the United States* (2021): **nap.edu/25968**
- *Accelerating Decarbonization of the U.S. Energy System* (2021): **nap.edu/decarbonization**
- *Communications, Cyber Resilience, and the Future of the U.S. Electric Power System: Proceedings of a Workshop* (2021): **nap.edu/25782**
- *Models to Inform Planning for the Future of Electric Power in the United States: Proceedings of a Workshop* (2020): **nap.edu/25880**
- *Enhancing the Resilience of the Nation's Electricity System (2017)*: **nap.edu/24836**

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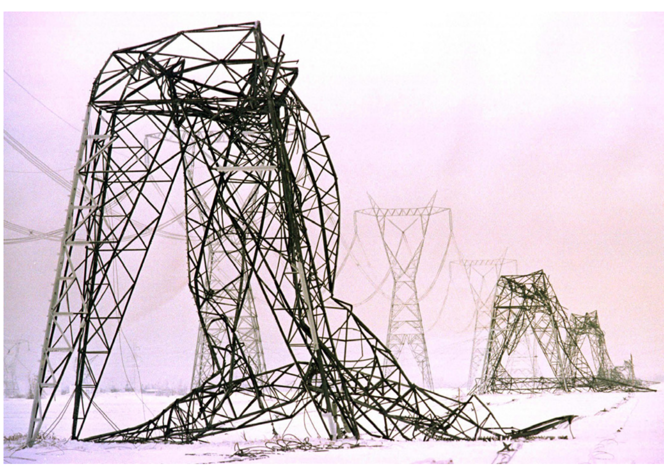
This Consensus Study Report Highlights was prepared by the National Academies' Board on Energy and Environmental Systems based on the report *The Future of Electric Power in the United States* (2021). This study was sponsored by the U.S. Department of Energy. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of the sponsors. Download the report at **nap.edu**.

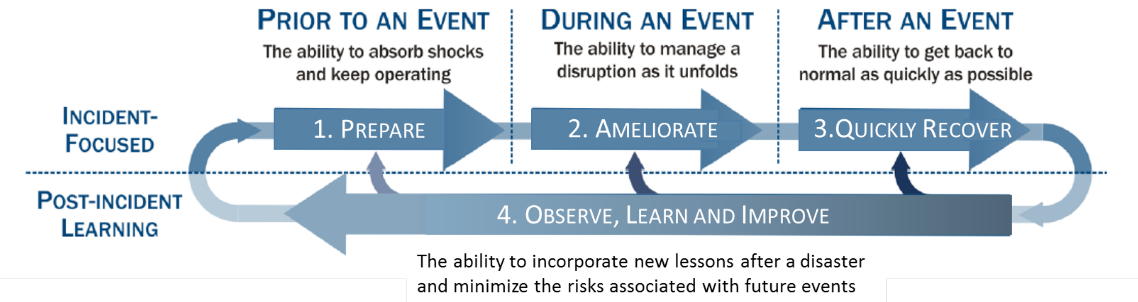
Enhancing the Resilience of the Nation's Electricity System

Electricity is fundamental to our nation's health, safety, and economic productivity. The electric grid powers our homes, essential services such as hospitals and emergency responders, and critical infrastructures ranging from communications to natural gas delivery. Nonetheless, our electricity system is vulnerable to diverse threats that can potentially cause extensive damage and result in large-area outages that take a long time to recover from. These events range from familiar natural disasters such as hurricanes, earthquakes, and ice storms, to low-probability events such as solar storms, to malicious human actions including cyber or physical attacks. When major outages happen, everyday tasks become difficult, economic damages can add up to billions, and lives can be lost.

In its 2014 appropriations for the Department of Energy, Congress requested that the National Academies of Sciences, Engineering, and Medicine organize a study to identify technologies, policies, and organizational strategies to increase the resilience and reliability of the U.S. electricity system. The study focuses largely on reducing the nation's vulnerability to large-area long-duration outages—those that span several service areas or even states and last three days or longer. Much can be done to make both large and small outages less likely, but they cannot be totally eliminated no matter how much money or effort is invested. To increase the resilience of the grid, the nation must not only work to prevent and minimize the size of



Massive damage to transmission infrastructure in southeastern Canada following the 1998 ice storm, which disrupted service to millions of people and required more than one month to recover from. SOURCE: Robert Laberge/AFP/Getty Images



A framework for critical infrastructure resilience. SOURCE: Modified from NIAC (National Infrastructure Advisory Council), 2010.

outages, it must also develop strategies to cope with outages when they happen, recover rapidly afterward, and incorporate lessons learned into future planning and response efforts.

THE ELECTRIC GRID IS ESSENTIAL, CHANGING, AND HETEROGENEOUS

Despite the changing technology, economic, and regulatory environment, the report finds that the majority of people will continue to depend on the organized, interconnected power system to provide resilient electric service for at least the next two decades. The grid is a complex, cyber-physical system composed of millions of physical, computing, and networked components that are spread across the continent. Most electricity is generated in large, centralized power plants, transmitted long distances at high voltages, and distributed to residential, commercial, and industrial consumers at lower voltages. The network of generators and high-voltage transmission lines—called the bulk power system—is subject to numerous operational, physical, and cyber security standards developed by the North American Electric Reliability Council with authority from the Federal Energy Regulatory Commission. High-voltage electricity from the bulk power system is converted to lower voltage at substations, and sent into thousands of electric distribution systems across the U.S. Distribution systems are regulated by state and local authorities or by oversight boards, and they exhibit tremendous heterogeneity in their resources, technological sophistication, ownership structure, and oversight mechanisms. The grid—composed of both the bulk power system and local distribution networks—is a system governed by many independent decisions and without a single organization in charge.

No single entity is responsible for, or has the authority to implement, a comprehensive approach for ensuring the resilience of the nation's electricity system. Because most organizations involved in operating and regulating the grid are preoccupied with short-term issues, they neither have the time to think systematically about what could happen in the event of a large-scale outage, nor do they adequately consider the potential consequences in their operations, planning, or research and development priorities. The U.S. needs a process to help all parties better prepare for and take action to mitigate the consequences of major outages. While the study's specific recommendations detailed below will incrementally advance the resilience of the nation's electricity system, these alone will not be sufficient unless the nation is able to adopt a more integrated perspective. Thus, the report recommends the creation of multiple resilience assessment groups to envision grid vulnerabilities and systemic impacts of large-area long-duration outages, provide guidance and support to decision-makers working to improve grid resilience, and coordinate across federal, state, and local levels.

STRATEGIES TO PREVENT OUTAGES AND MAKE THEM SMALLER

Resilience begins with preparative and preventative actions to make outages less likely. While the report focuses predominantly on large-scale outages, many of the approaches described may also reduce occurrences of small routine outages and increase utility performance on common reliability metrics. The report describes and recommends multiple strategies to make outages less frequent or smaller in scale, including:

- Improving the health and reliability of individual grid components, for example through preventative maintenance
- Designing the system's cyber-physical architecture to reduce critical dependence on individual components
- Rapidly providing better information and control strategies to operators through increased deployment of sensors and advanced data analyses

- Ensuring fuel diversity and avoiding over-reliance on any single fuel source, particularly natural gas

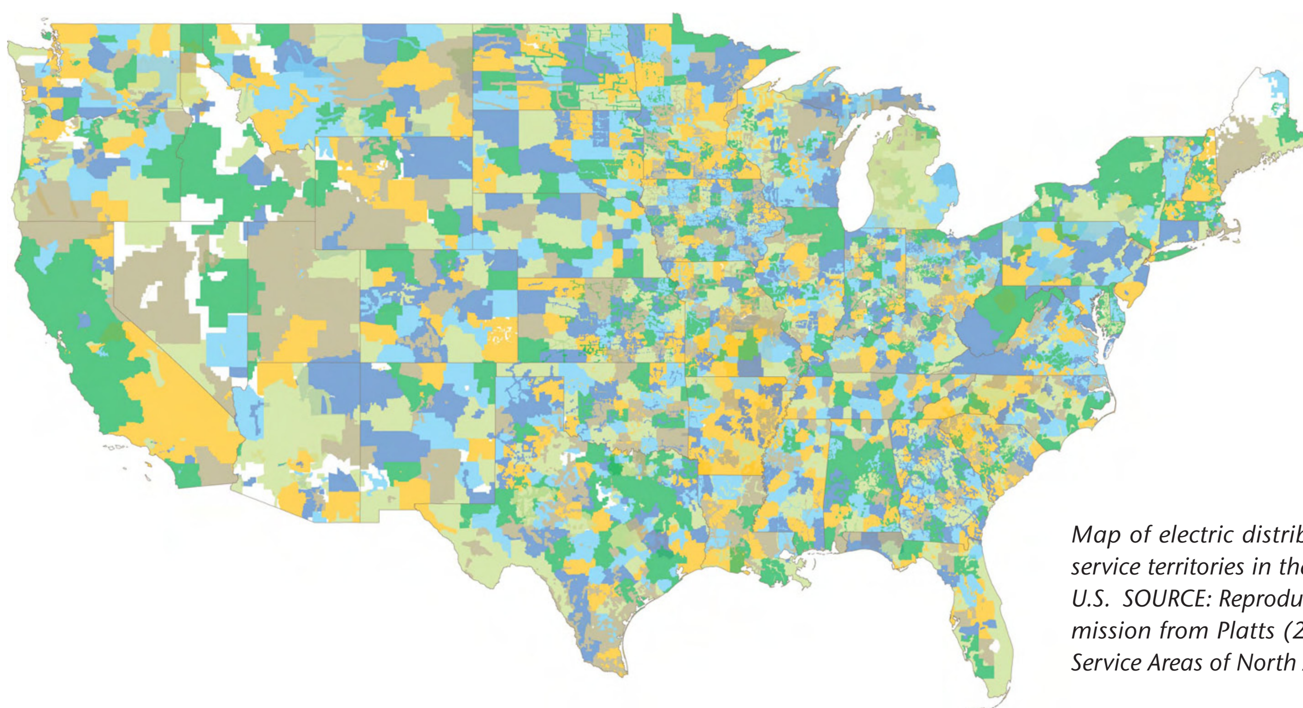
Many of these strategies focus on the bulk power system of large generators and high-voltage transmission lines, but the rapid pace of technological change for distribution systems in some regions is bringing additional opportunities to light. Distributed energy resources (DERs) and advanced controls on local distribution systems could play a larger role in preventing or limiting the spread of outages, for example through automatic reconfiguration of circuits to isolate broken components or using DERs to maintain power quality (e.g., keeping voltage and frequency within specified limits). A critical challenge in implementing any of these strategies on a meaningful scale is navigating the complex economic, institutional, and regulatory structures that oversee the grid.

STRATEGIES TO COPE WITH OUTAGES WHEN THEY OCCUR

The second stage in the resilience framework is to ameliorate the impacts of outages when they happen. While large-scale outages are rare, some will occur and restoration may take a long time. It is essential that utilities, public agencies, and society more broadly prepare for prolonged periods of electricity loss and the subsequent loss of vital public services including heating and cooling, water and sewage pumping, traffic control, financial systems, healthcare, and emergency response. The effects of power outages vary depending on the weather, the types and locations of customers affected, and the duration of the outage. A central theme of this report is the need to improve how different elements of society imagine the diverse consequences of prolonged power outages. The report recommends several strategies to help prepare for such scenarios, including:

- Improving the reliability of customer-purchased backup power equipment through more systematic testing and upkeep
- Re-evaluating government stockpiles and contracts for provisions of emergency power equipment and fuel during disasters
- Encouraging critical facility operators to pre-register information about their emergency power needs in a centralized and accessible database
- Exploring the potential for dynamic and selective provisioning of power to specific circuits or even individual meters on a circuit

Advanced distribution technologies including DERs, microgrids that can separate from the larger grid and maintain small pockets of power, and smart controls in substations and on individual distribution lines could provide partial service to critical facilities. The report recommends that state regulatory bodies and distribution system operators evaluate the legal,



Map of electric distribution utility service territories in the continental U.S. SOURCE: Reproduced with permission from Platts (2014), "Utility Service Areas of North America".

financial, and technical challenges associated with using customer-owned generation assets to provide partial service during major outages.

STRATEGIES TO EXPEDITE RECOVERY AND IMPROVE LEARNING AFTER OUTAGES

The last stages in the resilience framework involve recovery and learning from an outage. Effective restoration begins well before the disaster through preparatory activities including drills and stockpiling of key equipment. In the chaotic period after a large-scale power outage, utilities, first responders, and public agencies must work together to restore power quickly. In general, recovery entails an iterative process of assessing damage, coordinated activity to reconfigure, repair, and replace physical components, and a variety of activities to rebuild the cyber monitoring and control systems. However, in practice restoration processes are different depending on the event and the type of damage caused, such as whether the cyber monitoring and control system is functioning and able to aid in damage assessment. The report recommends several strategies to improve restoration activities for different damage scenarios, including:

- Developing standards for utility cyber control systems so that personnel on loan from other organizations can effectively participate in cyber mutual-assistance agreements
- Continuing research and demonstration into advanced power transformers that can provide greater operational flexibility
- Running restoration drills that engage key stakeholders from other critical infrastructure sectors such as communications, natural gas, and transportation
- Improving post-incident investigation practices to better learn from major outages and improve recovery processes for future outages

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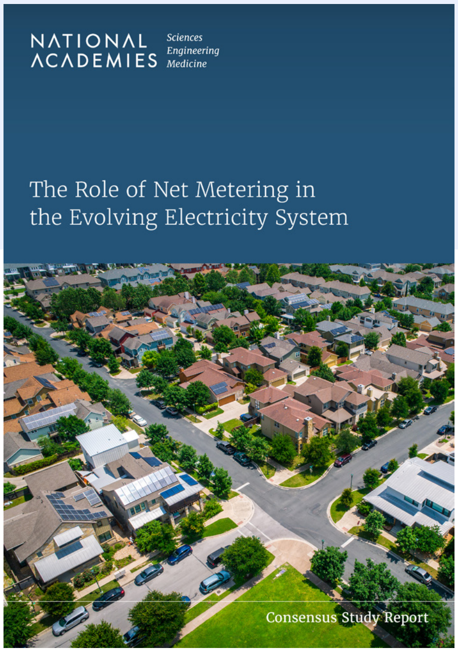
Consensus Study Report
Highlights

The Role of Net Metering in the Evolving Electricity System



Over the past three decades, changing economics, innovations in energy technologies, new policy objectives, and increasing customer expectations have driven fundamental shifts in the electricity system, including the growth of clean distributed generation (DG) such as rooftop solar. Net metering has been instrumental in supporting DG adoption but integrating the growing number of clean DG systems installed by residential, commercial, or industrial electricity customers is posing challenges for the grid. Given the many ways in which the electricity system and technology are changing, net metering must also evolve.

At the request of Congress and the Department of Energy, the National Academies convened a committee of experts to explore the issues associated with net metering, including the medium-to long-term impacts of net metering on the electricity grid and customers. This report, *The Role of Net Metering in the Evolving Electricity System*, examines how net metering must change to continue to support and advance a decarbonized, equitable, and resilient electricity system.

UNDERSTANDING NET METERING

Net metering is a billing mechanism that compensates electricity provided to the electrical grid by customers with DG, such as solar panels on their property. When a customer's solar panels are producing more electricity than the building is using—for example, perhaps when the occupants are away from home, few appliances are turned on, and the sun is shining—then excess solar-generated electricity can be fed back into the grid. It has supported the deployment of behind-the-meter (BTM) DG to achieve a variety of objectives—clean energy, resource diversity, carbon reduction,

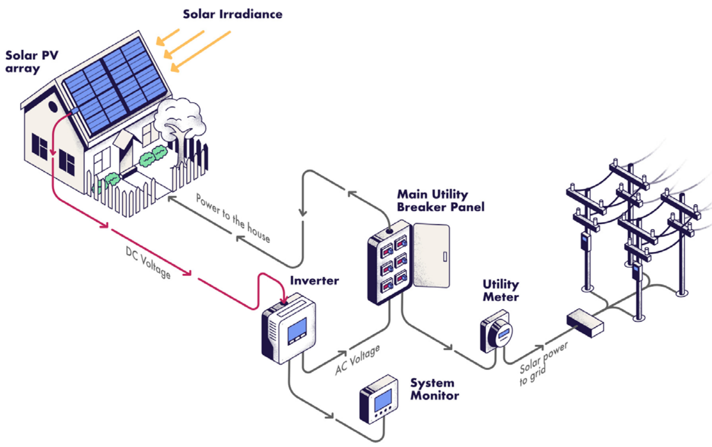


FIGURE 1 Technical configuration of a behind-the-meter rooftop solar system.

economic development, equity, and resilience—as well as customer expectations for choice and savings.

The most common type of household DG in the United States is a rooftop solar photovoltaic net-metered system. These systems provide customers with options for producing their own power and managing their energy bills, driving down the costs of renewables as the markets expand and technologies improve, and producing power with reduced carbon emissions.

NET METERING: TRENDS AND TENSIONS

In its early stages, when the costs of DG systems were high and deployment low, net metering provided important support for rooftop solar. The past decade has seen rapid advancements and cost reductions in solar and other DG system technologies, making these systems more affordable for many households. In many jurisdictions, net metering policies combined with multiple solar support mechanisms and financial incentives have further improved the customer economics for solar. As a result, larger numbers of customers have adopted rooftop solar systems and participate in net metering programs.

The growth in rooftop solar challenges the traditional approaches of planning, designing, funding, and maintaining the electricity system. Customers face uncertainties from changing prices, rate structures, and reliability and resilience of supply. Grid operators and utilities grapple with variable demand, hard-to-predict operational conditions, changing customer and policymaker expectations, and evolving regulatory and utility business models.

Mechanisms for compensating solar customers vary widely across the country with differences among state legislation, regulatory decisions, and implementation policies. State policymakers and regulators are considering variants and alternatives to traditional net metering that may better accomplish decarbonization, equity, and resilience objectives. Reforms in net metering policy have already been implemented or have been under active consideration in over half of all U.S. states over the past few years.

NET METERING CONSIDERATIONS

The report examines the economics, equity, technology, and policy and regulation considerations of net metering policies and the role they play in the growth of DG.

Economics

Net metering provides a direct economic value to participating customers by compensating them for their DG production based on the underlying rate structure. Moving forward, to encourage the integration of rooftop solar and other DG into the electricity system to maximize benefits for all customers, DG should be compensated based on the value it provides to the electricity system, society, and the customers adopting it.

The report recommends that regulators **strive to develop retail rate structures—for both DG and non-DG customers—with usage-based energy prices that correspond as closely as possible to the social marginal cost[1] of producing and delivering electricity** while recognizing other competing rate-design objectives. In the absence of economically efficient rate structures for all customers, the committee recommends **implementing changes to the net metering mechanism for DG customers, with DG compensation levels set at or near the social marginal cost of electricity production and delivery.**

[1] The incremental cost to the company supplying an additional unit of the good or service *plus the costs of any externalities*, such as pollution, that result from that incremental supply.

Equity

Low-income households, populations of color, and renters are less likely to adopt rooftop solar and participate in net metering than other customers. Thus, net metering can play a role in alleviating—or exacerbating—existing inequities associated with electricity supply and delivery across the United States. To remove barriers to the adoption of DG by, and reduce any cost consequences for, low-income and other disadvantaged customers and communities, the report calls for policymakers to build equity considerations into the design of net metering and its variants. The report also recommends consideration of alternatives to ratepayer-funded support for BTM DG, especially for low-income customers, such as legislative and taxpayer-funded programs.

Rates should be designed consistent with updated ratemaking principles, with particular attention to the equity impacts for customers least able to afford them. To help accomplish this, **utilities and policymakers should ensure that information about utility rates is easily available to all customers, and that all customers have a voice and can participate in the design of rates.**

Those involved in setting electricity rates **should consider both the impacts of the distribution of benefits and costs, as well as total benefits and costs when designing net metering policies and ensure that adequate data are collected and made publicly available to do so.** These benefits and costs should include and balance among other things: public health impacts, job impacts, land use impacts, and the future options that will be enabled or precluded.

Technology

Exponential advances in technologies related to metering, communication, computation, and power electronics have contributed to a steady increase in DG, which has implications on the larger electricity system. Modernizing the grid will require better integrating sources of renewable energy; incorporating advances in power electronics, storage, communications, and control technologies; and confronting issues surrounding cybersecurity and resilience. The report recommends that utilities make **investments in the distribution system to integrate, increase the visibility of, and manage (either directly or indirectly through price signals) increasing amounts of BTM DG such as rooftop solar, to ensure the continued safe and reliable operation of the grid and provision of grid services.**

The committee further finds **investments in distribution system technologies aimed toward integration of DG and Distributed Energy Resources must be accompanied by revisions in policies and state and federal utility regulations to facilitate the recovery of their costs.**

Policy and Regulation

Policies and regulations define the framework and market conditions that enable utilities and, as applicable, non-utility participants to invest in the distribution system for integrating BTM DG into the grid, with an opportunity to earn a reasonable rate of return on their investment.

The committee recommends state legislators, utility regulators, governing boards of publicly owned electric utilities, and others involved in making decisions about electric utility rates should consider that **DG technology costs and market maturity are at a stage both technically and economically where traditional net metering policies to support the deployment of DGs need to be assessed and revisited.**

The committee recommends that decision makers **rely on traditional ratemaking principles as updated to reflect the application of new technologies and service offerings, and the design of compensation approaches for the export of power from BTM generation according to principles that are consistent with how the utility values other sources of power that offer comparable energy, capacity, and other grid services to the system, which may vary by time and location.** Externalities, such as pollution, from some sources of power are generally unpriced, and in many jurisdictions, there are constraints on the ability of regulators to reflect externalities in utility planning and/or ratemaking. Sound economic principles would support the consideration of such externalities in utility regulation; policymakers should consider how to address such impacts in utility and other energy policies.

LOOKING FORWARD

Fully integrating BTM DG into the electricity system can lead to a cleaner, more resilient electricity system. Achieving this goal will require systematic, coordinated, and sustained investments. Redesigned rate structures and net metering need to be consistent with the basic principles of electricity rate design, balancing efficiency, simplicity, stability, fairness, and revenue adequacy. Thus, traditional net metering needs to be revised to achieve greater economic efficiency and equity. The report calls for a more intentional and integrated approach focused on maximizing benefits for all stakeholders. Policymakers and regulators should design net metering for the circumstances of their systems and markets, with input from affected stakeholders, and with an eye toward equity, resilience, and decarbonization.

The recommendations in this report provide guidance for net metering policies to compensate BTM DG for the value it provides, but not everything can or should be achieved through electricity rates. Broader societal goals may be best pursued through non-rate approaches. Additional supporting mechanisms that go beyond ratemaking will likely be necessary for attaining certain key objectives, especially equity. With a more open, transparent, deliberate, and intentional approach that leverages the locational, temporal, and contextual value streams of BTM DG, an evolved net metering policy could enable an electricity system that is more sustainable, equitable, and resilient.

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FOR MORE INFORMATION
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Division on Engineering and Physical Sciences

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Energy Equity & Justice Definitions

Assembled and compiled by Shay Banton (IREC)

Energy equity should be a core tenet and a central guiding principle of distribution system management. Prior to the workshop, we ask that attendees review the following definitions and principles related to energy equity and justice, and are prepared to discuss and apply such lens to all discussions.

Energy Equity / Energy Justice	The goal of achieving fairness in the social and economic participation within the energy system. It recognizes the historical and cumulative burdens faced by frontline and low-income communities, particularly Black, Brown, and Native people. To eliminate these disparities, energy equity centers the voices of these frontline communities in energy planning and decision-making, ensuring the fair distribution of clean energy benefits and ownership. Additionally, it aims to remediate the social, economic, and health burdens historically imposed by the energy system on these communities. (Energy Equity Project, 2022, & Initiative for Energy Justice [IEJ], 2019)
Recognitional Justice	**The "Who?"**. Ensures that all potentially impacted parties are identified, their diverse experiences recognized, and their perspectives are both validated and integrated into the energy decision-making process. Focuses on understanding the different types of vulnerability and specific needs associated with energy services among social groups, especially marginalized communities. (Lee & Byrne, 2019, & Chan, 2024)
Procedural Justice	**The "How?"**. Ensures the equitable and democratic involvement of all stakeholders in energy decision-making. It ensures that everyone has a seat at the decision-making table and that all voices are heard and considered equally. (Lee & Byrne, 2019, IEJ, 2019, & Chan, 2024)
Distributive Justice	**The "What?"**. Ensures the equitable distribution of both the benefits and harms of the energy system both in new investments and in addressing past inequities in energy development across society, particularly aiming to alleviate the disproportionate pressures affecting low-income communities and communities of color. (Lee & Byrne, 2019, IEJ, 2019, & Chan, 2024)
Restorative Justice	**The "Why?"**. Ensures efforts are made to repair injustices arising from energy decision-making in the past, pushing for the addressing of all potential harms and injustices and to implement prevention, mitigation, and restoration plans through compensation, restitution, and decision-making authority, even if what was lost is not fully recoverable. (IEJ, 2019, & Walker, 2006)

Additional Concepts:

You may find these other concepts helpful in advancing your understanding of what is and what is not energy equity.

Energy Democracy	Representing a shift from the corporate, centralized fossil fuel economy to one designed on the principles of causing no harm to the environment, supporting local economies, and contributing to the health and well-being of all people. It encompasses the idea that communities should have a say and agency in shaping their energy future including community ownership and control of energy production sources, democratic community decision-making in energy production and distribution, and the decentralization of power to empower those geographically, socially, and economically closest to the means of production. (Climate Justice Alliance, N.D., & IEJ, 2019)
Energy Insecurity	The inability to adequately meet basic household energy needs that manifests across various economic, physical, and behavioral dimensions, leading to hardships for households in fulfilling their essential energy requirements.
Energy Poverty	Energy poverty is the lack of access to basic, life-sustaining energy, which is essential for fulfilling fundamental needs such as heating and cooling, cooking, lighting, and communication. A lack of access to affordable energy can lead to increased risks of poverty, eviction, reduced food expenditure and calorie intake, and poor respiratory health, mental health, and sleep outcomes (IEJ, 2019, & Energy Equity Project, 2022)
Neoliberal Justice	Safeguarding of individual liberties, property rights, and the pursuit of self-interests with opportunity for voluntary environmental action (Ciplet & Roberts, 2017). Question: Although not explicitly stated, how does this principle manifest itself in today's management of the energy system?

Basic Structure of Distribution Planning

During one of the breakout sessions, we will examine how energy equity intersects with the stages of the distribution planning process. Below is a simplified structure of this process that will be examined:

1. **Set Planning Objectives** – What do we hope any new investments in the grid will achieve, whether that be improvements to reliability, grid modernization to simplify or expand grid management capabilities, or advancing energy equity.
2. **Collect, Assess & Understand Grid Conditions using Metrics –** Gather and analyze all necessary data about the grid and its customers to track progress towards the defined objectives.
3. **Forecast Load and DER Growth Trends** – Estimate how the load and generation dynamics of the grid will change over time, allowing for proactive investments in infrastructure that alleviate potential future issues.
4. **Identify Investment Options in Alignment with Objectives –** Evaluate the range of conventional and non-wires options available to address current and future issues while achieving overarching objectives.
5. **Prioritize and Select Investments** – Determine the priority of investments based on resource availability and alignment with the set objectives.
6. **Reflect and Revise** – Continuously improve the distribution planning process by identifying and addressing data gaps, and refining strategies based on new insights and feedback

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Section 6 – Electric Power/Energy Systems

Workshop

Creating A Sustainable National Electric Infrastructure While Maintaining Reliability and Resiliency of the Grid

Keck Center, 500 5th Street, NW, Room 101, Washington, DC
October 24, 2022

Workshop Planning Committee – Anjan Bose, Vijay Vittal, Jay Giri, Mark Lauby, Chanan Singh, and Murty Bhavaraju

WORKSHOP REPORT

Creating a Sustainable National Electric Infrastructure While Maintaining Reliability and Resiliency of the Grid

Over the past decade the electric power utilities in the United State of America (USA) have aggressively integrated low- and no-carbon generation resources into the nation's electric grid to achieve renewable portfolio targets set by various state regulators. In recent years, the federal government has also supported this effort through several measures, including tax incentives, research and development funding, and grants. These policy decisions, along with reductions in the cost of inverter and photovoltaic (PV) panel technologies, have made private investments into renewable variable energy resources (VERs) very attractive. For example, proposed projects that are waiting to be implemented in organized markets are currently overwhelmingly variable generation, leaning toward solar resources more than wind. Counter-imposed on this accelerated integration of VERs and with the reduced prices for natural gas, there is a move to shut down coal generation as quickly as possible and replace it with natural gas-fired generation or preferably with wind or solar resources. Customers, thus, are incentivized to install rooftop solar generation and participate in demand side management programs that include both energy efficiency and demand response.

Worldwide trends to slow climate change, along with its resulting impact on weather patterns and environmental conditions, have led countries to adopt decarbonization of the grid as an important priority. While implementation details may differ, electrical storage has been identified as an important component of solutions for addressing variability of renewable generation, even though it alone cannot be counted on for long-duration and widespread extreme weather and environmental conditions. In fact, there is a need for both local resources and transfers of energy across the grid to be provided by low- or no-carbon resources and complement each other. For this to occur, the design of the grid must change to accommodate renewable VERs and electrical storage. This includes integrating potential but unproven technologies, such as small modular nuclear reactors, hydrogen, or fusion energy sources. Coupled with broad electrification across all sectors of end users, these efforts are directed towards driving out carbon-intensity from demand applications and have necessitated coordinated planning of all elements to provide reliable, resilient, safe, and cost-effective electrical energy delivery.

Although the public discussion has mostly centered on changing the generation mix of the grid from mostly fossil-fuel to solar and wind resources, the profound impact that such a change has on the grid's behavior and performance has been discussed mainly among those responsible for the planning and operation of the grid. The non-linear behavior and performance of the grid is a function of the millions of interconnected components that comprise it. The present-day grid has evolved over more than a century and the planning and operation functions have been adapted by engineers over the same timeframe to the evolving changes. If the generation and electrical storage technologies are changed very rapidly as intended, significant attention needs to be paid to identify and study the challenges that will be encountered and to develop new planning and operational processes to represent the behavior and performance of the transforming grid. Electrification of transportation, residential and commercial heating, and other industrial and agricultural sources of carbon will further affect the grid and reliability goals. Enhancing the grid to support higher levels of reliability is essential for the benefits of electrification to be experienced, as society becomes more dependent on electricity for all its energy needs. Optimal integration of renewable VERs requires expanding and modernizing the transmission and distribution (T&D) infrastructure with significant capital and capacity investments.

Presently, ownership of the grid is fragmented and regulated by all the states over which it operates; however, it's planning, and operation is coordinated by the many actors enacting policies, regulations, and standards to ensure grid reliability and resilience. For the near-term, as the present grid transformation takes place, engineers must understand the grid's changing behavior and performance to develop new guidelines for planning and operations. Conversely, for the long-term when the grid is at the intended zero or near zero carbon state, the challenges are expected to be very different. This end point must also be investigated to make the appropriate preparations, thereby requiring further changes in regulations and standards for coordination.

This workshop, held under the auspices of the U.S. National Academy of Engineering, is premised on the belief that adequate attention has not been paid thus far to the technical guidelines and policy issues required to transform the planning and operation of the grid. While the grid is well on its way to being transformed to achieve decarbonization goals, if changes in planning and operations do not keep up with this transformation and its associated increasing uncertainties, the reliability and resilience of the grid could be severely affected. Extreme weather events between 2018 and 2022 that impacted millions of people in California and Texas, serve as timely examples highlighting the inadequacy of traditional planning and operation practices, where uncertainty or unavailability of generation and transmission energy margins impacts the ability of the grid to deliver the energy where it was needed.

Extreme weather events or environmental conditions appear to be a distinct trend that is frequently disrupting the electricity supply. Hurricanes, tornadoes, high and low temperature events, high or low winds, droughts, and forest fires are all parts of this trend. The reliability standards that are used today to plan and operate the grid are preventive in nature and have served the desired intent well. These standards are based on synchronous machines with rotating mass that are directly coupled with the grid. However, these machines are being replaced with inverter-based resources (IBRs) such as wind and solar, which are decoupled from the grid, with IBRs and associated controls requiring tuning to address essential reliability services. The relatively recent focus on "resiliency" is an attempt to consider how best to recover from the damage caused by such extreme events that appear to be happening with increased frequency. As fossil-fired units, which generally have long-term fuel storage on site, are being replaced with VERs, whose output is uncertain, can vary over time, and is sensitive to extreme weather and environmental conditions, it is not surprising that a new perspective is needed on how the grid operates. In fact, emphasis is now being placed on energy being delivered (time and megawatts available) as the output varies over time based on weather and environmental conditions, rather than just capacity (megawatts) where fuel was assumed to be available when reliability studies were performed, and the system operated.

The power industry currently uses many best voluntary practices and mandatory reliability standards for recovery, including emergency operation plans, system restoration coordination, black start resources, and other similar efforts. However, these will need modification, and new reliability standards may be required to assure current or higher levels of resiliency in the future as electricity becomes the dominant energy source. Further, state regulators have developed metrics for resiliency, which may also need to be revisited as the impacts from the loss of electricity increase, particularly when it is the sole source of energy.

The Electric Power/Energy Systems Section (Section 6) of the U.S. National Academy of Engineering organized this one-day workshop to discuss the reliability and resiliency of the transforming grid. The 40 invited experts from industry, government, and academia represented planners, operators, regulators, and researchers. The agenda for the workshop and the list of participants are in the Appendix. Some of the detailed discussions were held in three breakout groups – 1) generation adequacy, 2) planning and operations, and 3) resiliency. The final set of conclusions were generally agreed upon by the entire group of participants.

At the culmination of the workshop the attendees agreed on a list of challenges facing the planning and operation of the nation's electric grid, while the grid architecture is being radically transformed by the rapid changes in the generation technologies, infrastructure investments either delayed or not approved, and the nature of the load resulting from electrification of other sectors (e.g., transportation, commercial, industrial) to decrease overall greenhouse gas emissions. These challenges, in technical, regulatory, and policy areas, are listed here, together with some recommendations to manage the challenges so that the reliability, resiliency, efficiency, and the economy of the electricity supply to society is not disrupted.

1. Regulatory Challenges

The four components of the electric power system, generation-transmission-distribution-load, are regulated differently under the jurisdiction of separate entities. Prior to restructuring of the industry in the late 1990s, most generation was owned by vertically integrated electric utilities that were fully regulated by state regulators. In exchange for an assurance of cost recovery, these state regulated utilities had an obligation to serve. The result was that utilities and state regulators ensured investment in all the elements of the power system to ensure reliability, including the energy supply chain (the fuel system) that serves the generators.

Restructuring unbundled the industry in many areas of the country, with the result that a significant portion of the electrical energy production today comes from merchant generation (sited at both the transmission and distribution levels), which has the opportunity to recover its costs from the FERC or state/provincial regulated wholesale markets, but with

no guarantee of cost recovery. Restructuring and wholesale competition has resulted in significant innovation, cost efficiencies, and emission reductions, but it has also had an outcome on how reliability is achieved, as discussed immediately belw.

The operational performance of merchant generation and demand response providers, for example, is now dependent on various factor including the combined efficacy of NERC/regional/state reliability standards and the performance incentives presented through market designs. Therefore, investors in merchant generators and distributed resources may be motivated to limit investments in reliability/resilience to those that are either required due to mandatory standards, or where they believe their costs can be feasibly recovered with suitable profitability through the market. Currently-effective reliability standards that are sufficient for a vertically integrated industry with low penetrations of variable generation are no longer sufficient for a restructured industry that has high penetrations of VERs interconnected at both the transmission and distribution systems. Reliability standards and market designs are evolving to reflect the changing resource mix, through complex stakeholder and regulatory processes at both the federal and state level. However, due to the complexity of those processes, the standards and market designs are relatively slow to respond to the rapidly changing operational dynamics of the electric power system. Consequently, there are a number of reliability needs that are not yet specified in reliability standards, or specified and priced in electricity market designs.

Despite the disaggregated nature of the regulatory system that sets standards and market rules, the physical reality is that the four components of the power system are synchronously interconnected and events on any one of the components impacts all the others. This is especially true when new generation resources (primarily VERs) are increasingly located in the distribution system. Although there is coordination of the interconnection of generation to the transmission and distribution systems and the centralized regional planning of the transmission system, there is currently little holistic coordination or planning across the four power system components to ensure reliability of the system as a whole.

This disaggregation results in significant reliability risks and inefficiencies. In order to mitigate these risks, FERC, NERC, and the state regulators must harmonize their reliability regulations, and market designs across the four components to ensure continued reliability and resilience of the existing and future bulk power system. Further, recent events have illuminated that energy adequacy is one of the most important dimensions of a resilient power system. Given the variability of the weather, a power system with a high penetration of renewable resources requires significant quantities of stable, controllable balancing energy inputs that can be converted to stable sources of balancing electrical energy. The natural gas system is currently the most significant, long duration, balancing energy input into the electric power system, and its importance is likely to grow during the transition, until such time as it can be replaced by other technologies. Also, the reliability of the gas system, particularly the gas distribution system, is dependent on the reliability of the electric system to support compression (i.e., pressure levels) and end uses of gas consumption. The interdependencies between these two energy subsectors are currently not recognized in reliability standards for either subsector. In summary, the regulatory oversight of the electric transmission and distribution systems and the interstate pipeline and distribution gas systems is too compartmentalized, leading to gaps and significant reliability risks.

The compartmentalization of regulatory responsibilities of the different interdependent and interconnected components of the electric infrastructure and energy subsectors was a logical outcome of the structure of the bulk power system until the second decade of the twenty-first century. Since the 1960s, the power system was characterized by large central station generation with onsite energy storage (hydro, coal, and nuclear), interconnected by long distance, high voltage interstate lines. Electrical power was delivered from the transmission system to local distribution networks. The interconnected grid offered significant benefits by reducing the need for reserve capacity to address unit random failures and ramping up to address changes in generation, demand, and frequency support across the interconnections. However, there were also risks that emanated from this interconnection, which needed to be addressed. This realization spurred the formation of NERC in 1968 after the 1965 blackout. NERC developed voluntary criteria for the planning and operations of the bulk power system to ensure continued reliable operation. This trend continued, along with the advent of markets. The Energy Policy Act of 2005 (EPAct 2005) formalized the need for an Electric Reliability Organization (ERO) after the 2003 cascading blackout emanating from the U.S. Midwest. EPAct 2005 authorized FERC to certify one entity as an ERO (in 2006, FERC certified NERC as the ERO) responsible for developing and enforcing mandatory reliability standards that support the reliability and security of the interconnected bulk power system. The federal reliability statute explicitly excludes facilities used in local distribution and prohibits reliability standards for the expansion of generation and transmission capacity. Thus, the states generally retain jurisdiction for transmission, distribution, and generation siting and construction (except for cooperatives and municipals), while the FERC/NERC has jurisdiction over interstate reliability performance.

Compartmentalization of regulatory oversight could pose a significant obstacle to the development of consistent and overarching regulatory policies and standards that would ensure the reliability, economy, and resiliency of the nation’s entire electric infrastructure. Such policies and regulatory standards should incorporate a holistic assessment of the nation’s electric infrastructure system including generation no matter where it is interconnected, along with transmission, distribution and loads, as well as interdependencies like those experienced with the natural gas subsector.

Reliability of the bulk power transmission system is regulated by FERC and the ERO since the bulk power system cannot be planned without some knowledge of the generation being interconnected. Requirements to track planned generation and generation adequacy, which are generally based on capacity of the unit, vary across regions and states. There is significant concern, after some recent load curtailments, that resource and energy adequacy are not being tracked accurately. Namely, adequacy was historically tracked when the capacity of a unit was considered at full or some derated state output; however, this analysis did not include fuel conditions, but rather random failures of unit components. The transforming grid, on the other hand, has significant uncertainties under long-term, widespread weather and environmental conditions when loss of fuel/energy sources (wind, cloud cover, smoke, and other similar reasons) or too much fuel (e.g., wind cut-off speeds) occur simultaneously over large areas and long durations. At one time, capacity could be counted upon to provide both the energy and essential reliability services needed to sustain a reliable grid. With VERs, however, capacity is necessary, but not sufficient to guarantee that energy and essential reliability services are available to meet consumer requirements, unless alternative energy sources are planned for, and investments are made to take up these deficits. Simply derating wind or solar capacity over time periods ignores the simultaneous impacts of widespread, long duration weather or environmental conditions.

Reliability of the distribution systems is regulated by the state through state regulators. As mentioned above, in the past the distribution system was a passive receiver of power from the grid, and except for demand side management options, it was not considered in the planning and operation of the bulk power system. But, today, generation sources are increasingly being connected at lower voltages. This not only affects distribution planning and design, but with generation being connected to the transmission and distribution systems, the planning of the two can no longer be done separately and must be coordinated to ensure reliable operation of the bulk power system. Of course, the generation activated on the distribution system can help ameliorate the impact of events on the generation-transmission system, and vice versa. Importantly, the regulatory standards for generation, transmission, distribution, and demand must be harmonized to leverage the gains from VERs on the decarbonization generating resources.

Coordination between FERC, NERC, and state regulators is needed to develop reliability regulations for the entire grid. Although there are 50 separate state regulators, the owners of distribution systems generally follow similar best practices and approaches. State regulators already coordinate on various aspects through the National Association of Regulatory Utility Commissioners (NARUC). Coordination processes between FERC, NERC, and NARUC, therefore, is vital to decide which reliability standards are needed to support the planning and operation of the entire grid.

The above compartmentalization of standard setting and regulatory oversight, coupled with the rapid deployment of new technologies, creates new risks. These risks are compounded by the fact that many of the traditional analytical tools that are used to plan, design, and operate the transmission and distribution systems will not be adequate for the decarbonized, decentralized, and digitalized grid that is envisioned. As many of these analytical tools are guided by reliability standards and rules-of-thumb, such as the generation capacity adequacy requirement of one event per 10 years, or the ability to withstand single contingencies (N-1), there is greater urgency to develop new regulatory criteria and standards that contribute to a highly reliable and resilient grid.

Although the electric grid, from generation to load, is very closely coupled and cannot operate without coordination, it is not isolated from the rest of the energy supply chain and is intricately dependent on the fuel supply system, including coal and gas supplies, and the temporal availability and sufficiency of water, solar, and wind energy. Recent disruptions, especially in Europe and Asia, have pointed to the need for more attention to the coordination of these fuel supply chains, and the importance of regulatory agencies that oversee the electric grid that can ensure better coordination of these other energy subsectors. Further, new available alternatives must be considered, such as new long-distance high voltage transmission that can carry energy from where it is available to where it is not.

Although the existing reliability standards have served society well, increased incidences of extreme events, especially weather and environmental conditions, require enhanced reliability standards that address the performance of an evolving resource mix and one that can withstand extreme events, while, at the same time, enhance recovery from such events.

The reliability standards for the electric grid have continued to evolve over the decades to keep up with grid developments. In fact, the rapid pace of decarbonizing the grid is transforming the very nature of its architecture for connecting generation, transmission, distribution, and loads, thanks to the use of many new technologies and increasing interdependencies. Based on this, reliability standards must also be modernized quickly to keep up with the changes. Time is of essence. Recognizing a complete synchronization would likely require Congressional action, the present structure of federal and state regulations will also have to change. These critical policy challenges led to the following recommendations from the workshop participants.

Recommendation:

1. Need federal and state regulatory structure coordination and collaboration. This can be achieved by enhanced coordination between state regulatory agencies, NARUC, and FERC.
2. Need regulatory policies that account for interdependent transmission and distribution planning and operation. Reliability standards for the bulk power system and the distribution system should complement each other. Existing reliability metrics in distribution systems like SAIDI or SAIFI measure resilience; however, there are few to no mandatory reliability standards at the distribution level that address the integration of Inverter Based Resources (IBRs) and local energy storage (e.g. distribution connected batteries). Investment decisions based on these metrics and targeted resilience levels may need to be revisited as climate impacts and fuel uncertainties increase.
3. Energy availability must be addressed within the regulatory process.
4. Consideration of extreme events, climate change, and inclusion of resilience is essential in the formulation of new standards.

2. Policy

Many states and other government entities have established policies like the renewable portfolio standards (RPS). Further, recent actions by the US Federal government have provided incentives and rebates to support accelerated interconnection of VERs. These policies often include dates for shutting down or retiring existing conventional generation plants as well as installing new renewable generation. These scheduled retirements should be carefully examined and coordinated to ensure that sufficient amounts of energy and essential reliability services are adequate, and the system reliability and resiliency are

assured at all times. This does not mean there is a need to slow integration of VERs. Rather, sufficient energy reserves will be needed to address uncertainties resulting from VERs availability. These reserves and essential reliability services can be obtained in a number of ways (e.g., transmission additions, short-term ramping capabilities from bulk electric storage systems, demand-side management, and other such means) if the appropriate incentives are created (either through standards or market incentives) and a sufficient amount of time is provided to allow for the market response. Scheduled retirements also need to be coordinated with interconnected neighboring states as transmission circuits, markets, and balancing areas cross state lines.

Individual states have regulatory authority over the investor owned utilities within their boundary and have taken the lead in decarbonizing the grid by mandating the time-lines towards less dependence on fossil fueled generation. In order to provide the same level of reliability, the replacement of fossil-fired generation plants by solar or wind generation necessitates that renewable generation provide the energy and ancillary services that the fossil generation provided. Because the sun shines and the wind blows only part of the time, the capacity of renewable generation and/or adequate transmission infrastructure must be built to support this requirement, and the excess energy generated must be stored/accessed for the times when the solar radiation or wind is absent. Moreover, the renewable generation and storage must have the ability of providing frequency response and voltage control to the same degree of effectiveness as conventional generation.

Although the engineering needed to provide these equivalent essential reliability services from renewable generation is quite well understood, there are certain aspects that have not been taken into account when these policies were established. It is easy to understand that solar energy can be sold into the market at cheaper prices than fossil when the sun is shining. Industry will also have to buy energy and other ancillary services from storage devices when the sun is not shining, and these prices will be much higher. In addition, the energy storage capacity has to be even higher to support a storage capacity buffer to cover periods when VERs cannot produce. Additionally, if the system is experiencing widespread, long duration conditions, additional sources of energy and essential reliability services will be needed to ensure reliability and that resilience is sustained.

The grid is interconnected, and many organizations operate the grid across state lines. Although energy crossing state boundaries can be measured, many essential reliability services are not always part of the organized market, e.g. inertial stability or voltage control are provided by generators but are not specified in market designs, and therefore these services are not priced, and generators are not compensated for these services. This is further complicated by the fact that different policies in neighboring states makes it difficult to engineer and compensate the reliability of the interconnected system.

There are many forms of energy storage, ranging from fuels to electro-chemical storage in batteries, to hydro generation. The market will select the most efficient form of storage, if the storage requirement is specified. While short duration storage is very efficient for handling day-to-day contingencies and fluctuations, long duration energy storage is critical in ensuring that a resilient power system is able to withstand extreme weather and environmental conditions.

These challenges led to the following recommendations from the workshop participants:

Recommendation:

1. Clear specification of reliability standards for the interconnected power system, such that reliability and resilience is maintained even when neighboring states choose not to coordinate their electric energy policies.
2. Coordination of exit and entry of new capacity is much more difficult in areas that have restructured, because the decision to retire and/or build is voluntary, and not controlled by central planning. Capacity accreditation methods should therefore ensure that new entrants are valued in accordance with their ability to deliver energy when required for grid reliability, and market designs should appropriately value the required reliability services, including ensuring grid reliability and energy adequacy.
3. Organization of reliability standards around the planning, operations planning, and operation timeframes to ensure sufficient amount of energy is available to address predetermined scenarios providing a design and operating basis of the grid.
4. Electrification of transportation, heating and other industrial processes will lead to significant load growth. Most power systems will transition to become winter peaking and/or exhibit much more load volatility between seasons, and day-to-day variability as both production and energy storage becomes further decentralized. Much of this growth is caused by inefficient application of heating sources such as resistive strip (baseboard) heating, or inefficient air conditioner/heat pumps, when cold conditions are experienced, especially in areas which traditionally have not seen extreme cold conditions. Further, decarbonization policies, standards and market designs should account for these dynamics. Development of resilience planning and/or incorporation of enhanced resilience requirements in standards, addressing training and messaging (including consumers) and assuring that interdependent infrastructures (gas, water, transportation) are considered.

3. Markets

Generation is deregulated in large portions of the US and in those areas, electricity is bought and sold on electricity markets. Existing energy, capacity and ancillary services markets are run by the Independent System Operators (ISOs) or Regional Transmission Operators (RTOs) and regulated by FERC. The market rules are being enhanced to integrate distributed resources (generation, controllable loads and storage), recognizing their ability to provide energy, energy reductions (demand response), and ancillary services as well as controllable loads and storage. Determining the best technical and regulatory practices is challenging, and this effort is lagging the pace of evolution of the resourced mix.

As generation resources are being connected to the lower voltage distribution systems, the markets design are being improved to allow these distributed energy resources (DER) to bid into the wholesale market (e.g. FERC Order 2222). Similarly, demand side management (DSM) is a major tool for energy efficiency investments and in managing the peak load periods with demand response on both the transmission and distribution systems, and these active load entities are also looking for ways to participate in the market. The present state of the markets can take into account transmission level congestion issues by explicitly modeling the transmission network in the market clearing process. However, it is not clear that the transmission network models can be extended to include distribution feeder models. The congestion issues of the distribution system may remain invisible to the wholesale market or the bulk power system operator, thus potentially creating significant reliability issues on both the transmission and distribution systems.

With the increased penetration of IBRs it is critical to ensure that IBRs can provide essential reliability services to the electric power system. Traditionally, the power grid has relied on the stored mechanical energy in large generators' rotating masses (inertia) and other tools and technologies such as central control coordination to maintain grid stability and balance during moderate disturbances. As more renewable generation using IBRs without inertia are deployed, there will be a growing potential to see a greater imbalance between generation and load. While conventional, synchronous generators have operating reserve margins and "naturally" compensate for the imbalance, IBRs could react faster than conventional generation in balancing load and generation through improved management and coordination with system needs. Smart inverters need to have reserve margins and be controlled at the system level to effectively balance generation and load, requiring coordination and appropriate market mechanisms. This will require the long-term planners and operational planners change the way they interconnect resources. They will need to design and coordinate controls at the three-phase level, managing the growing complexity, and amplifying the need for innovation in control system, and cyber system research.

Finally, although FERC regulates the electricity markets and the reliability of the bulk power systems, the reliability and operation of the distribution system is under the authority of the state regulatory agencies. The DER and DSM modules connected to the distribution system in aggregate play a major role in the reliability and operation of the bulk power system but are not required to meet NERC reliability or cyber security standards. Either this gap must be addressed, or the bulk power system will have to carry additional reserves to cover larger contingencies.

These challenges led to the following recommendations from the workshop participants:

Recommendation:

1. The integration of the DER and DSM into the market by using third-party aggregators may provide market benefits but can potentially create reliability, resilience, and security issues for the distribution and the bulk power system. The distribution operator must have some oversight of the market results to guard against distribution level congestion, and potential stability challenges. The distribution operator must have direct visibility of the controls being used by third-party aggregators on distribution level DERs and DSM.
2. Coordination of wholesale and retail rate design along with reliability standards is required.
3. Develop incentives for resilience services with renewables and storage.

4. Develop incentives for renewables that interconnected with contributions to reserve margins. Much like "spinning reserves" or "hot-start reserves," these resources could be quickly pressed into service when reserves are needed to offset losses of energy in other parts of the system.

4. Long Term Planning

The consequence of restructuring was that no single organization had the responsibility to assure resource and energy adequacy. Without knowing the location of generation, transmission planning by the ISOs and transmission owners (TO), is more challenging. FERC, NERC, the states and the ISOs are trying to address these challenges through improvements to both the planning process and the cost allocation methods for assuring cost recovery for investments needed to both enable and transmit clean energy. However, the transmission planning process is generally lagging the speed of the resource transition. This puts pressure during the operations planning and operations timeframes and there have now been instances of loss of load as a result of generation and transmission inadequacies. Extreme climate changes could also significantly impact power systems in the future. Planning that accounts for extreme climate change is a necessity – this implies creating sufficient resilience through the transmission and distribution planning process and resource/energy adequacy standards and mechanisms.

Building of generation and transmission often requires long lead-times because of the permitting and regulatory processes that vary significantly by location. It is not uncommon for projects to take a decade to complete, or worse, to be abandoned. Many of the processes developed for long-term planning of the grid in regions that have not restructured enable planners to plan both the transmission system and the resource mix simultaneously, e.g. the Southwest Area Transmission (SWAT). However, this type of planning is more challenging in regions that have restructured, since the long-term resource mix evolves organically in response to market and policy incentives and can change quickly with lower investments required for renewable VERs. In restructured regions the transmission planning process is evolving to both respond more quickly to the evolution of the resource mix (e.g., through cluster studies), or to proactively address future needs through investment in transmission to enable future renewable generation (so called "public policy" transmission). The need to ensure energy adequacy, or resiliency, is not yet explicitly considered in the transmission planning process in either structured or restructured regions. This may become necessary as uncertainties grow resulting from interconnection of large amounts of renewable VERS, which are impacted by wide-spread, long-duration weather events.

The long term distribution planning is also facing challenges because more variable generation, especially rooftop solar, is being installed. The anticipated increase in electric vehicles and the conversion of other non-electrical energy consumption (e.g. cooking and heating) can also significantly increase distribution line loading.

Recommendation:

1. Advanced stochastic metrics, such as LOLE and HLOLE and acceptable extreme scenarios are needed to plan the future system to support reliable and resilient operation of the bulk power system.
2. Long-term planning should account for and consider the interconnection between regions and off-shore wind projects.
3. Improve coordination between planning and operation at two critical interfaces; a) transmission and distribution and b) electric power systems and gas (and other fuel) systems.
4. Organize reliability standards around the planning, operations planning, and operations timeframes to ensure sufficient amount of energy and essential reliability services are available to address predetermined scenarios providing a design and operating basis for the grid.

5. Technical Challenges

The rapid transformation of the grid is made possible by the introduction of new technologies associated with renewable VERs, bulk electricity storage systems, and a significant portion of the load projected to include electric transportation. The application of these technologies and electricity substitution for other energy sources in commercial and industrial processes will change the nature of the system. Seamless integration of these new technologies requires solving many technical challenges of planning, design, and operation. Moreover, the grid being a system of systems, the addition of numerous new components changes the system behavior.

As described above, IBRs (generation and storage) can balance load and generation quickly if there is reserve margin available. This approach requires the appropriate grid architecture, including control technology to facilitate the transition from traditional forms of generation to carbon-free generation. Smart inverters need to be controlled at the system level to achieve this goal, which requires new tools, significant changes in existing practices, and appropriate communication infrastructure. Three major technical challenges are mentioned here as these have an impact on policies and regulations.

5(a). Modeling and Analysis

Renewable VERs have now become an integral component of the generation mix, and by their very nature are inherently variable and uncertain. Understanding and characterizing the nature of this uncertainty, and how it changes existing practices is important for a range of applications in planning, design, and operation. With their continued evolution, extreme events pose a higher level of significant risk to power system reliability, resiliency, and security, as their output is sensitive to weather and environmental conditions. There is a critical need to accurately model scenarios for extreme events and incorporate them into the planning and operations framework. With the large investment in measurement technology more data is available across interconnections. Use of such data for validation and verifications of models is essential.

As power systems continue to evolve due to increased inter-relationships between the supply segment and the delivery grids, it is becoming increasingly important to plan the system holistically by integrating generation resources and T&D. However, there are no tools and process for integrated generation and T&D planning and investment prioritization.

Ideally, new technologies should not be installed for use until verified models are available for simulation studies. Additionally, the installed technologies must perform as modeled in the simulation studies, or adjustments made to harmonize and rationalize any differences. This has become a serious a problem in the transmission system, as transmission planners need to change the way they validate the new generator's impact on reliability to incorporate three-phase electromechanical or electromagnetic transient models, when in the past they only used positive-sequence models. This has resulted in a number of reliability issues when VERs are not riding through common faults creating serious events and near misses. Further, large quantities of distribution level resources can create unintended reliability consequences at both the distribution system and the transmission system, and these consequences are currently not, or at best poorly, considered in the distribution interconnection process.

Recommendation:

1. Develop a modeling framework for consistent and coordinated integrated decision making of states, ISOs, RTOs, distribution operators and market participants. These tools also need to extend simulations to hybrid electromagnetic transients and phasor domain analysis.
2. Tools for static and dynamic modeling all the new technologies like IBRs, storage devices, new electronic controllers, digital protective devices, communications, and other such components are needed.
3. Develop new tools, practices, and processes for integrated resource and T&D planning and investment prioritization.
4. Training is required so planners can use the new and existing modeling tools.

5(b). Power System Reliability – Energy Availability

Energy availability (otherwise know an energy adequacy) is a critical component of power system reliability. Given the large diversity in both the generation and load in the system and their changing characteristics, metrics, and design based scenarios that support the planning of future systems that in turn support the reliable operation of the bulk power system are needed. These metrics and scenarios need to capture size, duration, and frequency of various weather and environmental condition events. Significant attention must also be placed to consider the role of transmission in the reliability analysis process. The impact of active load shaping through implementation of demand response and energy efficiency investments also needs to be considered. A backbone transmission system can help to smooth out the variability of renewable power through diversity with energy transported from locations that have excess to areas that are deficient. The need for such a backbone and sufficient storage facilities should be studied.

The one day in ten years loss of load probability standard suited system planning needs with large rotating machines, which are fairly independent of fuel concerns and resistant to impacts from extreme weather and environmental conditions and coupled with low penetration of VERs. These assumptions are no longer valid with high penetrations of asynchronous VERs and sensitive gas-fired generating plants.

Probabilistic reliability assessments need to be coupled with extreme design based scenarios to ensure that not only those events of high frequency are addressed, but also the "tail" events, which can have severe impacts, even though they may be low probability.

Recommendation:

1. Revisit the efficacy of one day in ten years loss of load probability standard that is based on daily peak loads, which was in turn based on random failures of large capacity units with little or no consideration of fuel availability.
2. Ensure that both capacity and energy are available to support operation including quantity, and location is important with significant penetration of solar and wind generation
3. Probabilistic reliability assessment must account for the uncertainties in generation and demand and should account for the impacts of both the transmission and distribution systems.
4. Implement grid architecture, with communication infrastructure and smart inverter and grid controls for leveraging reserve margins available from IBRs.

5(c). Power System Reliability - *N*-1 Contingency Analysis

The *N*-1 contingency analysis has remained the basis of NERC operating and planning standards since the inception of these standards. With the changing generation and load mix, and the higher incidence of extreme weather events and environmental conditions due to climate change, there is a need to revisit this premise for both transmission and generation contingencies. For example, should ***N-1*** include predetermined extreme weather events and environmental conditions?

Recommendation:

1. Given system uncertainty and need for consideration of *N-k* scenarios, the *N-1* contingency criterion needs to be re-evaluated to account for the strong correlation between contingencies and evolving environmental and weather conditions that the system must operate under.
2. The contingency definitions should be extended from individual components to consider loss of distribution feeders, regional solar or wind, and aggregated load components

6. Resiliency

There are currently no universally accepted metrics for resiliency and no quantitative NERC standards on resiliency. The NERC reliability standards both minimize the probability of an outage and ensures that industry is ready to recover from events. However, they do not

specify how and what duration is acceptable as these investment decisions are made at the state regulatory level. Standards are needed to plan and design the grid to be restored within an agreed upon time after an outage caused by an extreme event. Extreme weather and environmental condition events resulting from climate change are increasing in frequency and intensity as evidenced by long-duration extreme temperatures, droughts that impact hydro availability and wind events caused by more powerful hurricanes and tornadoes. Similarly, standards are needed for withstanding a deliberate cyber-attack, which is quite different in nature than a weather or environmental event.

The value of resilience metrics lies in their ability to be benchmarked and compared across industry participants to facilitate continuous improvements. However, there is no "one-size-fits-all" solution for resilience metrics and investments as they are dependent on various factors (regional, functional, regulatory, and business). Although it is not possible to have simple, industry-accepted resilience metrics addressing all-inclusive events affecting resilience, it is important to identify individual parameters and events and associated system-dependent metrics. Those metrics could be then applied based on pre-defined priority weights and factors and by using the pre-defined framework to facilitate the investment decision process.

The previous five sections also address issues that are applicable to resiliency and several of the recommendations above apply to resiliency. However, because policies, regulations, and standards are not yet universally available for enhancing the resiliency of the grid, it is worth separately emphasizing this point.

Recommendation:

1. Grid resiliency standards, based on pre-defined framework and performance expectations, should be developed for all to follow.
2. Resilience plans for the restoration from extreme events, addressing training and messaging (including consumers) and interdependent infrastructures (gas, water, communication, transportation), should be mandated.
3. Overall T&D grid hardening is needed, including telemetry and solutions such as covered conductors, composite poles, tripping the circuit before the conductor hits the ground.
4. Research is needed to advance additional solutions with the transforming grid.

Appendix

NATIONAL ACADEMY OF ENGINEERING®

Creating A Sustainable National Electric Infrastructure
While Maintaining Reliability and Resiliency of the Grid
Workshop
Keck Center, 500 5th Street, NW, Room 101, Washington, DC
October 24, 2022

Final Agenda

8.00 AM – 8.30 AM	Registration with Breakfast	*Pre-function Area*
8.30 AM – 9.30 AM	Welcome Vijay Vittal, Regents Professor, Arizona State University Introduction Anjan Bose, Regents Professor, Washington State University Mark Lauby, Senior Vice President and Chief Engineering, NERC Vijay Vittal Framework of the workshop and breakout groups	*Room 101*
9.30 AM – 12 PM	Breakout group presentations and discussion	*Room 101, 102, 104*
10.30 AM	Break	*Pre-function Area*
10.45 AM	Discussion continues	*Room 101, 102, 104*
Noon – 1 PM	Lunch	*Pre-function Area*
1 – 2 PM	Continue breakout group discussion and finalize priorities and issues to be addressed.	*Room 101, 102, 104*
2 – 3 PM	Report out from breakout groups	*Room 101*
3.00 PM – 3.30 PM	Break	*Room 103*
3 – 5.00 PM	Wrap up discussion from breakout group input. Prioritize identified issues and challenges for inclusion in workshop report.	*Room 101*

Confirmed Attendees to NAE Section 6 Workshop

No.	Name	Affiliation
1	Derek Bandera	MISO
2	Emanuel Bernabeu	PJM
3	Gil Bindewald III	DOE
4	Anjan Bose	WSU
5	Terry Boston	Grid Protection Alliance
6	Robert Bradish	AEP
7	Daniel Brooks	EPRI
8	Jay Caspary	Contractor to DOE
9	Yonghong Chen	MISO
10	Joe H Chow	RPI
11	Jonathan First	FERC
12	Matthew Gardner	Dominion
13	Jay Giri	Independent Consultant
14	Eduardo Ibanez	GE Gas Power
15	Marija Ilic	MIT
16	Ali Ipakchi	OATI
17	Mark Lauby	NERC
18	Chen-Ching Liu	VPI
19	Clyde Loutan	CAISO
20	James Momoh	Howard University
21	Sasan Mokhtari	OATI
22	Rana Mukerji	NYISO
23	Jens Nedrud	Puget Sound Energy
24	Damir Novosel	Quanta
25	David Ortiz	FERC
26	Thomas Overbye	Texas A&M
27	John Pespisa	SCE
28	Michael Rib	Duke Energy
29	Jim Robb	NERC
30	Pedro Arsuaga Santos	GE Renewables
31	Matt Schuerger	Minnesota PUC
32	Chanan Singh	TAMU
33	Branden Sudduth	WECC
34	Richard Tabors	TCR
35	Paul Turner	GSOC
36	Mani Vadari	Modern Grid Solutions
37	Vijay Vittal	ASU
38	Gordon van Welie	ISO - NE
39	Dan Woodfin	ERCOT
40	Nan Xue	Siemens