

Abstract

The U.S. electric grid is a vast physical and human network connecting thousands of electricity generators to millions of consumers—a linked system of public and private enterprises operating within a web of government institutions: federal, regional, state, and municipal. The grid will face a number of serious challenges over the next two decades, while new technologies also present valuable opportunities for meeting these challenges. A failure to realize these opportunities or meet these challenges could result in degraded reliability, significantly increased costs, and a failure to achieve several public policy goals.

This report, the fifth in the MIT Energy Initiative's *Future of* series, aims to provide a comprehensive, objective portrait of the U.S. electric grid and the identification and analysis of areas in which intelligent policy changes, focused research, and data development and sharing can contribute to meeting the challenges the grid is facing. It reflects a focus on integrating and evaluating existing knowledge rather than performing original research. We hope it will be of value to decision makers in industry and in all levels of government as they guide the grid's necessary evolution.

One of the most important emerging challenges facing the grid is the need to incorporate more renewable generation in response to policy initiatives at both state and federal levels. Much of this capacity will rely on either solar or wind power and will accordingly produce output that is variable over time and imperfectly predictable, making it harder for system operators to match generation and load at every instant. Utilizing the best resource locations will require many renewable generators to be located far from existing load centers and will thus necessitate

expansion of the transmission system, often via unusually long transmission lines. Current planning processes, cost-allocation procedures, and siting regimes will need to be changed to facilitate this expansion. In addition, increased penetration of renewable distributed generation will pose challenges for the design and operation of distribution systems, and may raise costs for many consumers.

Increased penetration of electric vehicles and other ongoing changes in electricity demand will, if measures are not taken, increase the ratio of peak to average demand and thus further reduce capacity utilization and raise rates. Changes in retail pricing policies, enabled by new metering technology, could help to mitigate this problem. Increased penetration of distributed generation will pose challenges for the design and operation of distribution systems. New regulatory approaches may be required to encourage the adoption of innovative network technologies.

Opportunities for improving the functioning and reliability of the grid arise from technological developments in sensing, communications, control, and power electronics. These technologies can enhance efficiency and reliability, increase capacity utilization, enable more rapid response to remediate contingencies, and increase flexibility in controlling power flows on transmission lines. If properly deployed and accompanied by appropriate policies, they can deal effectively with some of the challenges described above. They can facilitate the integration of large volumes of renewable and distributed generation, provide greater visibility of the instantaneous state of the grid, and make possible the engagement of demand as a resource.

All these new technologies involve increased data communication, and thus they raise important issues of standardization, cybersecurity, and privacy.

Decision makers in government and industry have taken important actions in recent years to guide the evolution of the U.S. electric power system to address the challenges and opportunities noted above. Yet the diversity of ownership and regulatory structures within the U.S. grid complicates policy-making, and a number of institutional, regulatory, and technical impediments remain that require action. Our main recommendations can be briefly summarized as follows:

- To facilitate the integration of remote renewables, the Federal Energy Regulatory Commission should be granted enhanced authority to site major transmission facilities that cross state lines.
- To cope more effectively with increasing cybersecurity threats, a single federal agency should be given responsibility for cybersecurity preparedness, response, and recovery across the entire electric power sector, including both bulk power and distribution systems.
- To improve the grid's efficiency and lower rates, utilities with advanced metering technology should begin a transition to pricing regimes in which customers pay rates that reflect the time-varying costs of supplying power.
- To improve utilities' and their customers' incentives related to distributed generation and energy conservation, utilities should recover fixed network costs through customer charges that do not vary with the volume of electricity consumption.
- To make effective use of new technologies, the electric power industry should fund increased research and development in several key areas, including computational tools for bulk power system operation, methods for wide-area transmission planning, procedures for response to and recovery from cyberattacks, and models of consumer response to real-time pricing.
- To improve decision making in an increasingly complex and dynamic environment, more detailed data should be compiled and shared, including information on the bulk power system, comprehensive results from "smart grid" demonstration projects, and standardized metrics of utility cost and performance.