Electricity Advisory Committee

TO: **Honorable Patricia Hoffman, Acting Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy**

FROM: **Electricity Advisory Committee**
Susan Tierney, Chair

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RE: **New Technologies Require a Modern Grid: Report on the U.S. Department of Energy Grid Modernization Initiative**

Introduction

The electric power grid is considered the largest and most complex man-made machine in the nation. The grid is critical infrastructure and disruption of its normal operation has a direct, detrimental effect on the economy, as well as on safety and convenience. Due to these interdependencies, planning for grid development must incorporate high levels of reliability, resiliency, and security not only against natural disturbances, but also against malfunctions or deliberate attacks. Today's power grid is already facing significant challenges: growing cyber and physical security threats, an increase in severe weather events, greater deployment of variable and distributed renewable resources, and growing penetration of digital and "smart" electronic grid technology.

Modernization of our electric infrastructure represents an important economic opportunity both to create domestic jobs and to meet the demands of a growing global market for internet-compatible sensors, meters, and other grid technology. Although the United States leads innovation for technologies that make the grid "smarter," countries like China and India are rapidly increasing their investments in grid research and development (R&D). These investments arise in large part to meet national electricity demand growth spurred both by rural electrification and by the conversion of some heating, cooling, and transportation loads from fossil fuels to electricity. Grid modernization R&D in the U.S. is critical to retain leadership in this global market.

To meet this need, DOE sponsors research programs on these technologies and on the issues surrounding their integration onto the grid. Although grid research is conducted throughout DOE, in 2011 the Grid Tech Team—composed of relevant program managers—was formed to coordinate and focus research toward agreed-upon overall goals for the grid. This effort resulted in the DOE Grid Modernization Initiative (GMI) being launched in 2015 with a Multi-Year Project Plan (MYPP). The first set of grid modernization projects under the MYPP was funded at $230 million to a National Grid Modernization Laboratory Consortium (GMLC) in 2016 consisting of 88 projects.

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The Electricity Advisory Committee (EAC) has been kept informed both of the evolution of the GMI and of the progress of the GMLC projects. This summary report consists of EAC observations regarding not only the national importance of conducting research on the grid, but also the special characteristics and uniqueness of grid research. The EAC further provides recommendations that supplement the goals already outlined in the MYPP.

Observations on the Electric Power Grid and Related Research

There are three loosely connected large power grids in the United States. Like other national infrastructures, portions of each power grid fall under various governmental jurisdictions. Moreover, much of these power grids is proprietary, with ownership shared by hundreds of private companies.

However, each of these power grids is so large that it can be thought of as a "system of systems" because its components, including generating plants or high-voltage transmission lines, are complex systems in their own right. The grid functions as an interconnected machine in which every component affects the characteristics of the whole system but the characteristics of the whole system is not just the sum of all the components. To plan, design, operate, and control a power grid—the whole system—requires system-level research that is qualitatively and quantitatively different from the research needed to develop new components. It is not enough to research how to integrate a new device (e.g., a new type of storage) into the grid. Necessary also is research on how integration of these storage devices into the grid will impact the functioning of the greater "system of systems."

This nuanced understanding of grid system behavior is critical to developing methods for grid planning, design, operation, and control as the grid evolves and incorporates more and different technologies: new generation types, new storage technologies, and more electronic devices (to interconnect the new generation, storage, and DC devices, etc). In addition to new power components, the grid is being overlaid with more sensors, communications, computers, and controllers, which on the one hand provide better monitoring and control of the grid but, on the other, increase overall system complexity. The analytical methods used to study and engineer the grid must accommodate this complexity. Planning and operation methods and associated software tools must keep pace with the modernization of component technologies being integrated into the grid.

R&D needed for the modern grid is qualitatively and quantitatively different from the R&D required for the component technologies. Differences in the magnitude of complexity are highlighted by the answers to key questions on grid functioning: How resilient? How secure? How flexible? The same questions can be asked of a component, but the outage across regional interconnected grid infrastructure because of a storm, a cyberattack, or an accident has a much bigger impact on society than the loss of one component, one house, or even one neighborhood. Examples include the 2003 blackout stretching from New York to Detroit and damage from Superstorm Sandy in New York and New Jersey in 2012, which had even more severe repercussions. Answering questions about how the grid changes with the addition of new technologies will require much more research.

Because the grid is part of the country's national infrastructure, its resiliency, security, and flexibility are considered a public good. There is incentive for inventing better grid components—e.g., better generators, transformers, and measurement sensors—as they can be sold in the thousands or millions and the inventor can directly profit. However, unless electric service providers are directly compensated for making the grid more resilient and secure, there is no existing financial incentive for the owners of the grid (who make money by selling energy) to do so. The benefits of more reliability and avoidance of blackouts accrue to society as a whole. Given this, reliability standards for the grid are maintained under the jurisdictional authority of the federal government, specifically by the Federal Energy Regulatory Commission. For the same reasons, the R&D on the grid is largely funded by the federal government and DOE is the agency with the jurisdictional authority to fund such R&D.

Since R&D for grid reliability and grid resiliency constitutes a public good—and because a reliable and high-functioning grid is so important to the nation's economy and security—the federal government has an essential role to play in supporting such grid-related research and development. If grid-level research were not federally funded, the gap would not be filled either by the states or by the private sector. Few states fund research on energy-related topics at all, much less on electric-system components or the resiliency, security, or flexibility of the grid. The benefits of such research are diverse and cross state boundaries; most states therefore do not include such research within their government budget priorities. The gap would similarly not be filled by private companies. As noted above, profit-seeking organizations lack the financial incentives to secure public goods. In addition, many challenges facing grid operation are too complex or too long-term to fit within the business-model and financial requirements of these firms. For example, the software development community has been clear that private companies will not attempt to develop components of next-generation grid control systems because optimization is prohibitively costly as long as the worldwide market for such products remains thin.

Recommendations

Grid Research Community

DOE's MYPP lays out an excellent plan for grid research and the GMLC projects are a good start for implementing the plan. The main distinction of this list of GMLC projects is that they form a comprehensive and cohesive set that together addresses the MYPP goals of a more resilient, secure, and flexible system. As the national laboratories are not the only organizations with expertise in grid research, the EAC recommends that the pool of researchers be broadened to include universities, vendors, and consultants who also work in this area. Although some power companies are already participating in the GMLC projects, more can do so. Bringing universities into the GMI also serves a secondary goal—developing the workforce needed to work on the sophisticated new technologies that are rapidly becoming part of the modern grid.

Simulation Platforms

Power grids are large and can span whole continents. Grids consist of all components, from generation units to customer appliances, as well as the sensors, communications, relays, controllers, and associated computers that overlay the power equipment. The planning and design of the grid require analytical software tools that can harmonize these components and their characteristics. Moreover, the development of operational methods and controls for the grid requires extensive off-line testing before deployment on the actual grid. Simulation is the most effective form of predictive modeling, yet the simulation capabilities available today can handle neither the size of the evolving grids nor the rapidly growing list of new technology components. Since the resiliency, security, and flexibility of the grid are important public goals maintained through government policy, the creation of simulation capabilities to conduct such research on this national infrastructure must be the government's responsibility.

The EAC recommends that the MYPP goals include setting up comprehensive simulation capabilities for the national power grids. Grid simulations have many layers of models, methods, applications, and data, but these do not need to be all in a single geographic location; they could take the form of a comprehensive and coordinated software library that can be linked seamlessly to provide the complete range of grid simulations needed. Given that the data for the national grid are sensitive information, DOE should also keep a library of anonymized or synthetic grid data that researchers can use to run experiments in the public domain.

Test Laboratories
While digital simulation of large grids is the only way to test large grid behavior, modeling of, individual sensors, controllers, or other new equipment may require the testing of actual hardware. In fact, most testbeds today are a mixture of hardware and software capabilities, often referred to as “hardware-in-the-loop” testing. The EAC recommends that the MYPP include the goal of sponsoring several qualified testing laboratories. Unlike the simulation capabilities suggested above that can be virtual, these would be physical laboratories that can also be interconnected. Several national laboratories and many private companies have developed such labs for specific purposes, and these could all become resources for testing and research of new technologies. DOE should ensure that all laboratories serving as research platforms are compatible with each other to simplify the setup and testing by third-party researchers.

System Technologies vs. Component Technologies
Since the grid is a collection of individual components, no clean demarcation exists between the research needed to develop new components and the research needed to plan and operate the evolving grid platform. Thus, the MYPP refers to the importance of developing new power electronics equipment, new types of storage devices, new transformers, for improving grid performance. The EAC recommends that for R&D planning, DOE should differentiate between component research and grid system research, allowing component research to be handled by the existing DOE program structure while the GMI could concentrate on leading grid system research. The EAC asserts that system research—critical to ensuring grid resiliency, security, and flexibility—needs a visible base within DOE and not be divided up among the different component research programs.

Grid Modernization and Policy
Policies on greenhouse gases, power plant and transmission siting, electricity rates, reliability criteria for planning, operations, and cybersecurity all play a role in influencing what the grid looks like. The EAC recognizes the importance of this and recommends that research on the grid include the development of methodologies and metrics that can help the regulatory agencies consider system-wide grid impacts in setting their policies. For example, there are no design targets for grid resiliency yet (unlike the ones for reliability targets), and research on grid resiliency would be useful for setting new standards in this area.

Conclusion

As critical national infrastructure, the electric grid must be resilient, secure, and flexible enough to handle changes in the generation mix, consumer demand, and new technologies. The modernization of the grid is central to achieving these aims because it will enable faster and more accurate responses to independent evolutions in the landscape of electricity generation, transmission, and distribution. The role of the federal government in R&D for the grid is essential as the lack of profit incentive in furthering grid resiliency, security, and flexibility will limit private sector efforts. More specifically, the GMI is critical because it increases the ability of the grid to adapt to the energy future. The MYPP and GMLC projects represent important DOE initiatives because they promote large-scale advancements in grid functionality and security, and DOE should continue investing in these initiatives.