

THE BOTTOM LINE

Grid modernization offers significant benefits to the quality and efficiency of service delivery in all grids, irrespective of the current level of modernization. These benefits include improved operational efficiency (reduced losses, lower energy consumption, etc.), reduced electrical demand during peak load periods, improved service reliability, and ability to accommodate distributed generating resources without adversely impacting system stability. Benefits of grid modernization also include improved asset utilization, allowing operators to squeeze more capacity out of existing assets and improving and workforce productivity.



Samuel Oguah is an energy specialist in the World Bank's Energy and Extractives Global Practice.



Debabrata Chattopadhyay is a senior energy specialist in the same practice.

Mapping Smart-Grid Modernization in Power Distribution Systems

Why is this issue important?

Regardless of a country's level of development, grid modernization can help utilities improve service

Why should countries where 75 percent of the population lacks access to electricity consider a strategy for deploying smart grids? Should they not focus first on increasing access? And would it not be better for a utility grappling with debt, power theft, and high technical losses to focus on getting the basics right rather than looking at defining a grid modernization strategy?

The answer is that smart grids are an essential element in improving efficiency that is relevant to utilities in all countries—from advanced utilities with robust grids to those whose grids barely keep up with demand. This note provides practical guidance for stakeholders in defining smart-grid goals, identifying priorities, and structuring investment plans. While most of these principles apply to any part of the electricity grid (transmission, distribution, off-grid), the note focuses on the distribution network.

Modernizing the grid can help utilities address issues in service delivery such as reducing technical and commercial losses, promoting energy conservation, managing peak demand, improving reliability, integrating high levels of distributed generation (such as mini-grids and power sources with variable output), and accommodating the rising use of electric vehicles (figure 1). To harness these benefits, it is essential that well-designed plans be developed for the implementation of smart-grid goals and objectives (Madrigal and Uluski 2015).

Even in underdeveloped grids, equipment is replaced either routinely or when equipment fails. By following a clearly defined road map for grid modernization, cost-effective smart-grid elements that yield the highest benefits can be used for these necessary replacements.

Smart elements in a grid will differ greatly depending on the state of the power system and the country context. A smart-grid roadmap will therefore vary considerably across countries, but smart technology is essential for successful modernization of any grid.

What are smart grids?

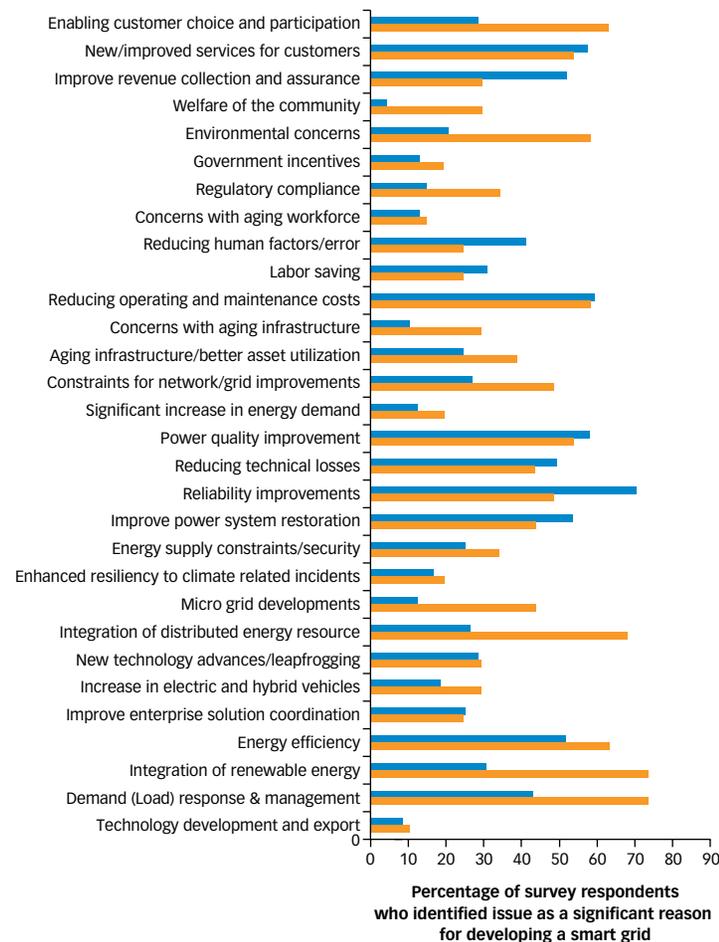
Smart grids are conventional grids enhanced by technology to enable digital communication among grid components and to increase operational flexibility

There is no common definition of a smart grid. Indeed, it is usually defined to reflect the specific requirements and needs of the implementing utility, because a smart solution for one utility may not be smart enough for another, depending on its level of development. A grid that intends to integrate a large share of renewables will require different modernization steps from a grid that plans simply to improve its reliability (see Figure 1).

A simplified way to visualize a smart grid is to think of it as having four main layers that can be combined to create features to improve the grid's ability to achieve defined goals:

“A grid that intends to integrate a large share of renewables will require different modernization steps from a grid that plans simply to improve its reliability.”

Figure 1. Reasons for developing smart grids cited by 66 power industry participants in 42 countries

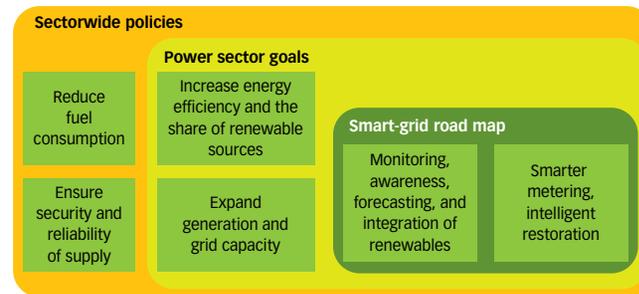


Source: ESTA Survey on International Smart Grid Drivers, undertaken for the U.S. Department of Energy, <http://www.estainternational.com/ESTA/Projects.html>.

- **“Hard” infrastructure.** This comprises all the physical components of the grid, such as the generation, transmission, and distribution assets that produce and deliver energy to consumers.
- **Telecommunications.** This includes all communication services (for example, wide area networks and field area networks utilizing optical fiber, leased lines, wireless connections, and so on) that enable applications to monitor, protect, and control the grid.
- **Data.** This includes systems necessary to ensure proper processing, utilization, and analysis of data.
- **Applications.** These are the tools and software technologies that use and process information collected from the grid for monitoring and protecting the grid, and for controlling the hard infrastructure layer.

Incorporating technology into conventional grids to enable digital communication among grid components can improve operational flexibility and performance in various ways. For example, in some grids, utilities have to send workers out to open or close circuit breakers, read meters, measure voltage, and gather other useful data. The components of a smart grid, by contrast, are equipped with integrated sensors to carry data and allow two-way communication, making it possible to remotely operate equipment or retrieve status information at the utility’s operations center.

Smart grids can therefore be seen as a conceptual goal whose achievement requires continuous modernization through the use of conventional and advanced digital technologies. However, they are not the panacea for all challenges faced by utilities. Although they enable energy sector objectives, they should not be viewed in isolation. For example, an overall energy goal might be to reduce fossil-fuel consumption through the introduction of renewable energy (such as solar or wind energy) in the power sector. The integration of large shares of renewables requires better grids equipped to deal with rapid system changes. Without these transformations, the grid will be a barrier to achieving sector goals. Put differently, the selection of smart components for the grid must be driven by the higher-level policy goals and should not be viewed entirely as a matter of technology enhancement (figure 2).

Figure 2. Smart grids in the overall electricity sector

Source: World Bank.

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What are the challenges in grid modernization?

Soft measures pose a greater challenge than hard measures

The most significant challenge to the deployment of smart grids is arguably the soft measures such as the legal and regulatory framework—the enabling environment—rather than the hard ones acquired through direct investments in infrastructure. The degree of importance of the enabling environment to the implementation of a modernization strategy will depend on the current state of the grid and the technology applications to be deployed. Regulations need to ensure, among other things, that (i) companies have the right incentives to pursue technologies that improve grid performance, (ii) the technologies introduced meet or exceed technical service delivery requirements, and (iii) those technologies can communicate with one another, allowing network modernization to progress smoothly without being tied to particular vendors.

Regulations are also needed to ensure the proper funding of modernization strategies. Depending again on the state of the grid, it may be necessary to institute cost-recovery mechanisms and to require the use of cost-efficiency principles designed to secure the long-term benefits of modernization, rather than to pursue narrowly focused projects designed to immediately reduce capital

costs. Regulations should provide financial incentives to the utility to perform well in delivering energy efficiency profitably as a core part of its business rather than as a marginal activity. Finally, regulations may have to include a mechanism to estimate and compensate for the revenue margin that may be lost in a successful energy-efficiency program.

Systems going through reforms or that have recently been restructured to unbundle generation, transmission, and distribution may find it difficult to capture the systemwide costs and benefits of grid modernization. For instance, some advanced smart-grid programs may lead to significant reductions in peak demand, which would have the effect of reducing the overall cost of supply and obviate the need for unprofitable investments in peaking generation. In so doing, however, the programs may cause retail companies to fear losing a significant part of their revenue. In such a scenario, more strategic cooperation is required between various systems and operators, as well as special regulatory approaches to help service providers stay viable despite reductions in energy sales (IEA 2011).

Another challenge is the ability of power system operators to work with modern grids. System operators who are experienced in working primarily with manual, paper-driven business processes may have difficulty adapting to a computer-assisted system. As an example, smart components pose the risk of data overload. Intelligent electronic devices (IEDs) are able to supply a wealth of information pertaining to the loading, performance, and operating status of each distribution element. The volume of information may lead operators to ignore information or, in the worst case, confuse operators into making incorrect operating decisions based on their assessment of the available information. To prevent such problems, capacity building should be considered as an integral part of a smart-grid strategy.

Additionally, the introduction of communication systems introduces the risk of cyber attacks. Unauthorized access to sensitive data and to the control center could disrupt the supply of power to customers, damage expensive energized high-voltage power apparatus, and pose a safety hazard for the field workforce.

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How do we meet these challenges?

A detailed smart-grid road map is fundamental to cost-effective modernization

The first step in reaping the untapped potential of modernizing the grid is to develop a comprehensive road map to shape decisions made in pursuit of defined goals.

To reduce the risk of failure, smart-grid planners should follow a step-by-step procedure to develop a holistic smart-grid road map that clearly responds to sector goals. The road map—a detailed description of actions to be taken by regulators, utilities, countries, or regions—should be complemented by equally detailed implementation plans to realize the ultimate smart-grid objectives (Madrigal and Uluski 2015).

The development of a road map is an iterative and inclusive process that also calls for regular updates to match system conditions. A road map focuses stakeholders on a succinct plan, sets a vision, identifies technology needs, supports better investment decisions, and provides a timeline for achieving goals.

The five steps in defining a smart-grid road map are:

1. Establish a long-term vision based on energy sector goals.
2. Establish a timeline, phases, and goals for each phase.
3. Define pillars of action to support each of the vision elements.
4. Determine policies, regulations, and technology applications for each time period and each pillar.
5. Define metrics for monitoring progress.

A good strategy should also include a strategy to build the capacity of the institutions and personnel who will operate the modified grid. This may require involving operators in all aspects of the planning and design phases and providing a comprehensive training program for all operators well in advance of system commissioning. Such a program minimizes the risks of overloading operators with data because operators are taught what to expect from the system and how to prioritize the data they receive.

Given the risk of cyber attacks, smart-grid road maps should include the development of a security plan to protect remote monitoring and control facilities from unauthorized access. Several international organizations are collaborating to address the issue of

cyber security in power systems. For example, the Joint Research Council of the European Commission has initiated the European Network for the Security of Control and Real-Time Systems (ESCoRTS) (IEA 2011).

With regard to distribution, the road map should reflect the state of the existing grid with reference to the following four levels of modernization:

- **Level 0: Manual control and local automation.** This is a situation that exists at many utilities in developing countries. Most processes are performed manually with little or no automation. Data communication facilities needed for more advanced data acquisition and control functions are absent. Protective relays, voltage regulators, and capacitor bank controllers may be mostly electromechanical devices, or in some cases electronic devices, or IEDs.
- **Level 1: Substation automation and remote control.** Electromechanical controllers, protection, and metering devices in substations have been replaced with IEDs and remote terminal units or data concentrators that acquire, store, process, and transmit information between IEDs and the control center.
- **Level 2: Feeder automation and remote control.** This level is characterized by extended remote monitoring and by advanced control of feeders, existing line switches, capacitor banks, voltage regulators, and other utility-owned equipment. It also requires an extensive network of one- or two-way communications with the IEDs mounted on feeders for improved control and decision making.
- **Level 3: Integration and control of distributed energy resources, plus demand response.** This level features energy storage, static volt-ampere reactive sources, and advanced communication and control facilities to effectively integrate and manage inflows from distributed energy sources. The Electric Power Research Institute in the United States has produced a good summary of the options and costs of smart-grid technologies (EPRI 2011).

Operational flexibility and associated benefits increase as a utility moves up the levels. These benefits need to be aligned with overall

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sector goals such as improved efficiency, reduced losses, improved reliability, and the integration of renewable energy resources. In developing economies where grids are often characterized by frequent outages and high commercial and technical losses, these significant challenges also represent significant opportunities, since smart grids can improve reliability, reduce losses, and, in some cases, lower the cost of service delivery.

Although some utilities (mostly in industrialized countries) followed a gradual progression from one level to the next by implementing new technologies as they became available, utilities in developing countries generally do not need to proceed one step at a time to the next-highest level on the four-point scale. An old electromechanical relay can be replaced by a state-of-the-art IED if it fits the business need of the utility. Or all new transmission lines can be equipped with telecommunication equipment such as optical fibers. This leap-frogging process is comparable to the transition from no telephones to cellular phones without passing through the stage of building out the infrastructure needed to support a wired telephone system. To do this in a cost-effective manner, however, requires systemwide planning, further underscoring the need for a modernization road map.

The increased use of mini-grids as a means of increasing access to electricity makes the need for a smart-grid road map even greater. Since a road map stipulates standards that ensure interoperability and standardization of equipment, it will be easy to integrate a mini-grid into the national grid if established regulations are followed (IEA 2011). Without this, a country could end up with mini-grids that cannot be connected to the national grid.

No single investment strategy for grid modernization applies to all electric distribution utilities, but five broad steps may be followed to define an investment plan.

- **Step 1. Identify business requirements.** The first step in creating an investment strategy for grid modernization is to develop a thorough understanding of the key business requirements that apply to the electric utility in the short term (the next three to five years) and in the long term (beyond a five-year horizon). This will provide a foundation upon which the functional and technical requirements for modernizing the distribution grid may be based. Common objectives include

improving efficiency, reducing demand, and accommodating distributed generation.

- **Step 2. Identify the current level of grid modernization.** The grid modernization strategy should leverage the distribution utility’s existing assets to the fullest extent possible. Therefore, gaining a thorough understanding of where the organization is today is an important first step toward grid modernization.
- **Step 3. Generate a list of potential projects.** The next step is to develop a list of potential grid modernization applications with the potential to address the organization’s needs and strategic goals.
- **Step 4. Perform a cost/benefit analysis.** It is then necessary to determine if the cost to implement each application and the associated risks are outweighed by the expected benefits over the life of the investment (10–15 years). As part of this step, the organization should perform a cost/benefit analysis and risk assessment of potential grid modernization applications, then develop a list of applications recommended for implementation.
- **Step 5. Create an investment plan.** The final step is to create an investment plan for the recommended applications—one that uses limited organizational resources (including labor and financial resources) in an optimal manner to achieve maximum payback on investment as quickly as possible and at an acceptable level of risk. In almost all cases, a phased implementation strategy is best. Projects that promise the greatest benefits should be completed at the earliest possible date. “Foundational” (enabling) elements—communication facilities, controllable devices, and so on—should be put in place to serve the needs of the application functions to be implemented during later phases.

In future project planning, the World Bank and other donors should propose the development of grid modernization strategies to clients and help them with the development of such strategies. The planning should highlight gaps in the regulatory environment that, if not closed, may impede modernization. In many cases, a good plan will be able to save significant time and money by absorbing lessons from around the globe and avoiding short-term solutions that have costly long-term implications.

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Live Wire 2014/1.

“Transmitting Renewable Energy to the Grid,” by Marcelino Madrigal and Rhonda Lenai Jordan.

Live Wire 2014/17.

“Incorporating Energy from Renewable Resources into Power System Planning,” by Marcelino Madrigal and Rhonda Lenai Jordan.

Live Wire 2015/38. “Integrating Variable Renewable Energy into Power System Operations,” by Thomas Nikolakakis and Debabrata Chattopadhyay.

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Madrigal, M., and R. Uluski. 2015. *Practical Guidance for Defining a Smart Grid Modernization Strategy: The Case of Distribution*. Washington, DC: World Bank. <https://openknowledge.worldbank.org/bitstream/handle/10986/21001/934380PUB-0978100Box385406B00PUBLIC0.pdf?sequence=1>.

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