Electric Power Grid Modernization Trends, Challenges, and Opportunities

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Background

The traditional electric power grid connected large central generating stations through a high-voltage (HV) transmission system to a distribution system that directly fed customer demand. Generating stations consisted primarily of steam stations that used fossil fuels and hydro turbines that turned high inertia turbines to produce electricity. The transmission system grew from local and regional grids into a large interconnected network that was managed by coordinated operating and planning procedures. Peak demand and energy consumption grew at predictable rates, and technology evolved in a relatively well-defined operational and regulatory environment.

Ove the last hundred years, there have been considerable technological advances for the bulk power grid. The power grid has been continually updated with new technologies including

- increased efficient and environmentally friendly generating sources
- higher voltage equipment
- power electronics in the form of HV direct current (HVdc) and flexible alternating current transmission systems (FACTS)
- advancements in computerized monitoring, protection, control, and grid management techniques for planning, real-time operations, and maintenance
- methods of demand response and energy-efficient load management.

The rate of change in the electric power industry continues to accelerate annually.

Drivers for Change

Public policies, economics, and technological innovations are driving the rapid rate of change in the electric power system. The power system advances toward the goal of supplying reliable electricity from increasingly clean and inexpensive resources. The electrical power system has transitioned to the new two-way power flow system with a fast rate and continues to move forward (Figure 1).

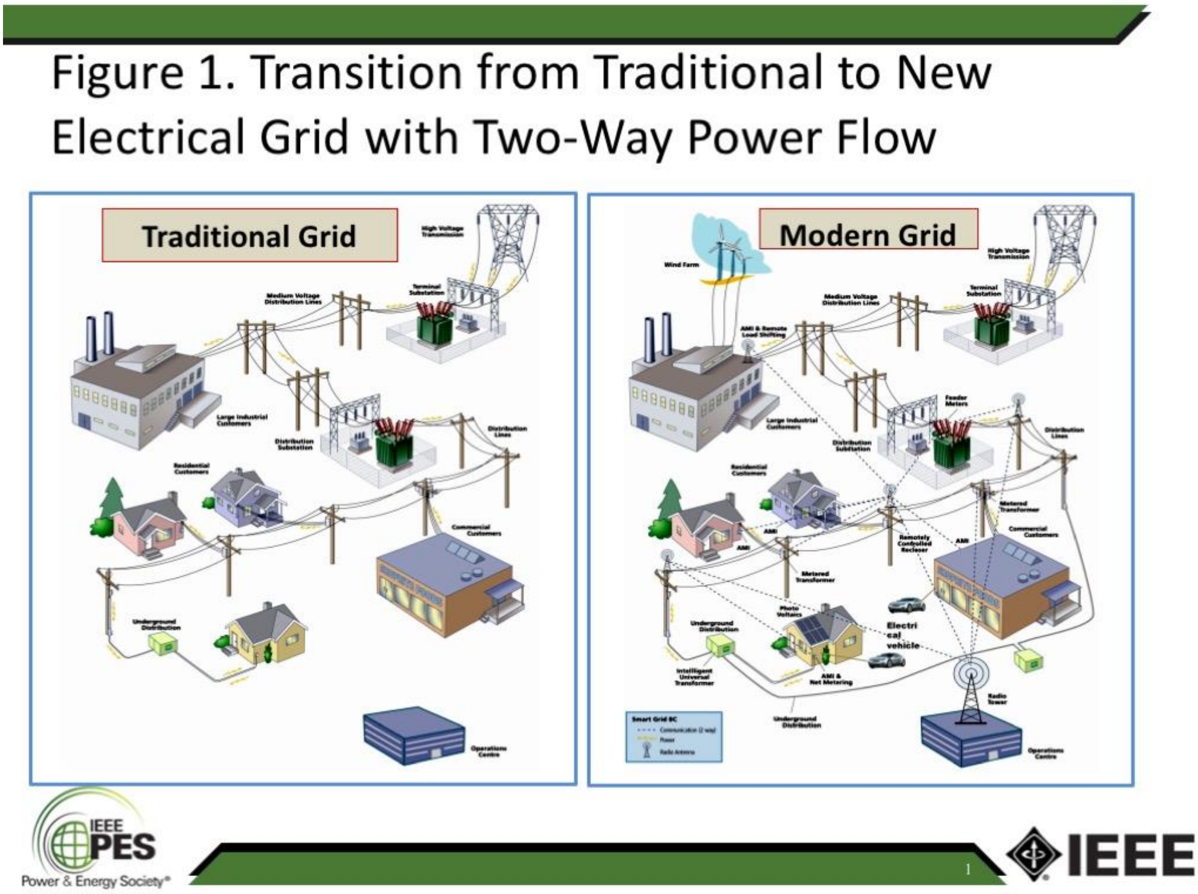

Figure 1. Transition from a traditional to new electrical grid with two-way power flow.

The re-regulation of electric power industries in the United States and elsewhere introduced wholesale electric markets. Competition shifted the risk away from rate payers to investors, reduced consumer costs, and supported rapid innovation. The advent of markets and environmental policies prompted significant changes in the fuel mix of generating stations that shifted from coal and nuclear generation to efficient natural-gas-fired combined cycle units. A tension exists between the wholesale electric markets and public policies that subsidize, or in other ways promote, the use of renewable resources, energy efficiency, and demand response. However, the economics of these technologies have become increasingly favorable, and their applications have resulted in lower costs to consumers and greater environmental sustainability. Recent developments include the advent of retail access and even distribution markets, which offer more consumer choices and business opportunities but complicate managing the electric power grid. Regulatory reform continues driving changes to the electric power industry.

The regulatory revolution helped spur technological development. The Internet of Things (IoT) facilitates more customer choice that can be managed locally, remotely, or automatically and enables changes in consumer behavior and expectations. The distribution system was originally designed and built to serve peak demand and passively deliver power through radial infrastructure. Today, however, many customers are increasingly using the grid as a means to balance their own generation and demand and also as a backup supplier when their locally sourced generation is unavailable. More and more, customers are becoming prosumers and expect to deliver excess generation back to the grid and be paid for it, without restrictions on their production. However, customers still expect the grid to be available to provide power when they need it. These competing interests have dramatically changed distribution system operation.

The digital revolution also manifests itself through dramatic improvements in monitoring and control equipment in the traditional power system. Additionally, innovative analysis techniques have allowed more rapid situational awareness to grid operators. Advances in material science and controls have led to new applications of power electronics; one example of new technology is smart inverters for photovoltaic (PV) systems that can actively interact with the distribution system.

Innovations in solar and wind generation and energy storage have resulted in both performance improvements and cost reductions. Increased sales as well as technological advances have reduced the pricing of solar panels. Several states in the United States, such as California and New York, and countries such as Germany, Spain, and Australia have ambitious goals for achieving high penetration levels of renewable generation and distributed energy resources (DERs) in the coming years. Regulatory policies, such as net-zero metering, can be used to encourage growth in PV installations. Net-zero metering allows consumers to sell surplus power to the grid and subsidizes the owners for installing PV panels. However, even consumers who have a net-zero footprint will often use grid power during cloudy days and at night, still relying on the availability of the distribution grid. Unfortunately, the net-zero metering policy causes customers who do not have solar panels to subsidize those who do, since the expansion and maintenance costs of the distribution system are included in the rate base. Therefore, customers who consume more electricity from the traditional grid bear a disproportionately larger share of the infrastructure costs. This effect is further exacerbated since PV panels are typically installed by consumers who are financially better off.

For example, the state of Nevada, which has one of the highest solar radiation resources in the United States, has an aggressive renewable portfolio standard (RPS) of 25% renewable energy production by 2025 and incentives that are intended to favor the adoption of renewable energy. Furthermore, very competitive pricing of utility-scale solar has favored the adoption of power purchasing agreements in Nevada to meet the RPS goals. In response, Nevada has recently changed its net-energy metering program to reduce incentives for new rooftop solar projects. Conversely, Florida rejected the rooftop solar amendment that would have paid for utility infrastructure through additional fees to rooftop solar customers in their energy bills. These examples of disparate approaches to solar power indicate a need for regulators to address how to monetize the use of the grid. Additional approaches will need to address both energy use and distribution system infrastructure costs for the continued success and growth of solar power installations.

One of the main drivers in the United States has been abundance of natural gas, as much of the new power plant capacity added in the past two decades relies on natural gas to generate electricity. This trend was followed by a significant retirement of coal and nuclear power generation plants that are deemed less economical than natural gas. The recent U.S. Department of Energy (DOE) Staff Report to the Secretary on Electricity Markets and Reliability (see https://energy.gov/sites/prod/files/2017/08/f36/Staff%20Report%20on%20Electricity%20Markets%20and%20Reliability_0.pdf) recommended that all energy sources be priced at their true costs; therefore, solar proliferation fueled by incentives may slow down except in states with aggressive

RPSs and favorable renewable generation environments (such as California, New Jersey, New York, and Hawaii). At the same time, as utility-scale solar has achieved parity with natural gas in markets with high wind/solar resources and the economics of solar and wind continue to improve, it is expected that removing subsidies will not significantly impact their competitiveness against gas.

These examples are from the United States. However, in any electrical system around the world, extreme care must be taken so that the adoption of renewable technologies and the shift in fuel sources do not undermine the reliability and resilience of the electric grid. The worldwide power industry needs to reliably generate its electricity, given the various environmental policies and economic considerations, while assuring that the reliability and resiliency of the electric power system is not negatively affected by this change.

Grid Modernization Needs

In achieving these goals, a key question is how much should be invested in the grid as more and more DER systems serve loads without utilizing the grid for extended periods of time. The reliability and safety of serving electrical power loads may potentially be negatively affected if the transmission and distribution (T&D) grid is not available or capable of providing backup for renewable power intermittencies. Therefore, increasing the ability of the T&D system to host and enable the use of increasing penetration levels of DERs is necessary.

Grid modernization and DER proliferation are certainly interrelated, but the latter is not a requirement for the former. Utilities such as Commonwealth Edison (ComEd) and CenterPoint, which operate in service territories with incipient penetration levels of DERs, have successfully implemented grid modernization initiatives with the purpose of improving grid reliability, resiliency, and system efficiency; addressing growing expectations regarding customer service; and replacing foundational aging infrastructure. For example, ComEd's Energy Infrastructure Modernization Act, which includes the deployment of 2,600 smart switches and 4 million smart meters, has been able to avoid over 4.8 million customer interruptions since 2012. An additional benefit of this modernized infrastructure will be to facilitate the transition toward a new paradigm that includes a high penetration of DERs.

Utilities operating in states such as California and Hawaii aggressively promote DER adoption to achieve RPS goals and move toward a modernized distribution grid at a fast pace. Furthermore, since an even larger-scale adoption of DERs is inevitable, given the planned achievement of grid parity by distributed generation in these markets, additions in grid modernization infrastructures and systems should be considered necessary investments to enable the normal operation of modern and future distribution systems.

The Grid of the Future

The electric power industry faces significant challenges in achieving grid parity. The successful integration of variable energy resources presents opportunities for a cleaner environment but poses issues that include an increased need for regulation, ramping, and reserves. Applications of HVdc and FACTS provide performance solutions, but they may further complicate network operation and planning. The need for network control becomes exacerbated by the large-scale growth of energy efficiency and demand utilizing inverter-based technologies, including applications of electric transportation vehicles. The development of demand energy resources and demand response presents additional changes to the distribution system that must then perform with power flows in two directions where, historically, power flowed in only one direction. Microgrids provide reliability and resiliency but also significantly change the physical attributes of the network.

While the electrical power system is becoming more distributed, and will continue to do so, it is important to note that today's interconnected grid began as a series of distributed grids. Interconnected grids were created to improve grid cost-efficiency, reliability, service quality, and safety. As technology advancements made it easier to deploy distributed renewable resources, the fundamental benefits of a connected grid still hold. While the present grid is very reliable, users will demand even more reliability from electric power delivery in the future, including resilience during major weather or security events. The integration of DERs and distributed grids can increase efficiencies in the use of the existing grid as well as become part of the overall development strategy to balance supply and demand uncertainties and risks with a variety of different resources, assuring resilient, flexible, and safe power delivery to consumers. Furthermore, innovative changes to the regulatory climate will also affect paradigms of the electric power business. Rates based purely on energy sales will rapidly diminish. Traditional utilities will transform into electricity providers that deliver services, such as installing distributed resources, aggregating customers who participate in the wholesale electric markets, and arranging for backup energy on demand.

Technology Makes It Happen

This is a time of rapid change for the electric utility industry. Advances in technology will meet the challenges posed by the grid of the future. The technology drivers for grid modernization include

- improvements in renewable generation resources and storage as well as electrical transportation
- improvements in monitoring, protection, and control and the accompanying software tools
- bringing electronic technologies and devices (particularly solid-state devices) to the grid, transforming the transitional passive, electrical, and electromechanical grid to be an active, electronic, electrical, and electromechanical grid with dynamic control.

Figure 2 shows how the electrical system components are changing.

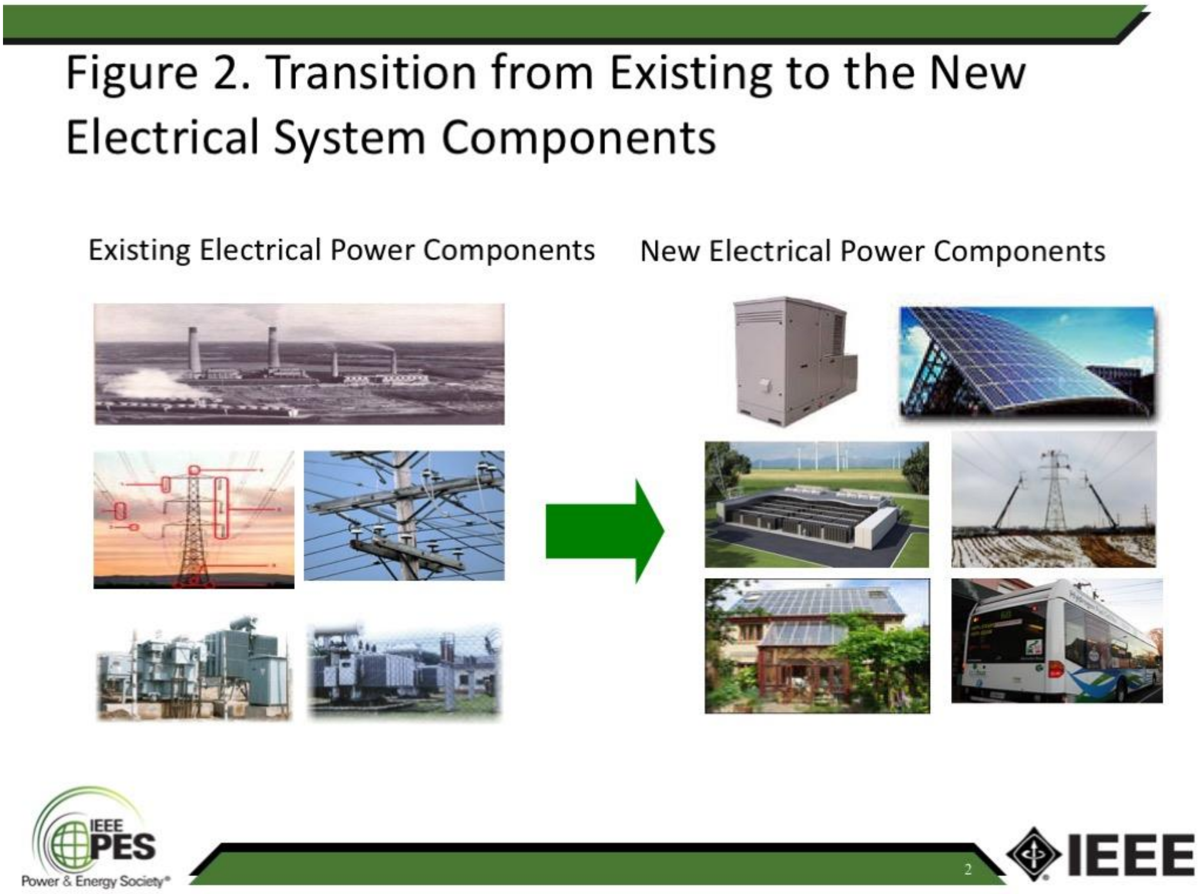

Figure 2. The transition from the existing to the new electrical system components.

Several of these innovations are discussed next.

Central Generating Station Innovation

The efficiency of central generating stations burning fossil fuels continues to improve. Combined cycle and other types of natural-gas-fired generators with heat rates under 5,800 BTU/kWh are now the norm. These generating units also provide improved flexibility, such as quick-start capability, which facilitates the integration of variable resources. The development of natural-gas-fired generators precipitates the retirement of less efficient coal- and oil-fired generation, which reduces carbon emissions. However, the modern gas-fired generators have lower inertias, which adversely affect the frequency response of the network. The interaction with the natural gas system, including scheduling, must also be addressed.

Hydro generators provide renewable energy but face increasingly stringent environmental restrictions that could constrain the operation of traditional technologies. Innovative hydro designs that use variable speed drives offer flexible and improved efficiencies of operation. Other new hydro technologies include marine and hydrokinetic types that capture the tidal and current power of the oceans; conduit hydro that places turbines in existing waterways, such as canals where there may be minimal environmental impact; and small hydro that can utilize existing dam infrastructure.

Wind and solar power development represents a very significant change to the traditional resource mix. Both produce emission-free energy at capital costs that continue to plummet. The increased installation of these resources over wide areas reduces the total variability seen by the overall power system. Modern designs improve the efficiencies and life of wind and solar resources and reduce maintenance costs. Important innovations in controls enhance voltage and frequency responses and facilitate the overall development of resources. The advancement of new onshore wind, offshore wind, and solar technologies continues at a rapid pace.

Transmission Innovation

The development of renewable resources often occurs far from load centers, which can necessitate increased transmission transfer limits. However, the variable nature of wind and solar resources, coupled with variable demand, exposes the transmission system to a wide range of operating conditions. New technologies provide improved utilization of limited rights-of-way and operation flexibility.

HVdc and FACTS

HVdc and FACTS utilize power electronics and are anticipated to grow exponentially. HVdc applications address the needs for the following:

- network controllability of real power, voltages, and auxiliary controls providing frequency regulation and damping dynamic oscillations and transient stability swings
- asynchronous interconnections
- transmission over long distances
- bypassing network congestion and injecting power at single points
- submarine applications
- satisfying right-of-way of constraints
- minimizing high short circuit contributions.

HVdc networks will become more common with the use of HVdc circuit breakers and control schemes. HVdc controls can now mimic ac circuit responses by changing post-contingency flows (see Figure 3**).**

Figure 3. A modern HVdc Facility. [Source: *IEEE Power & Energy Magazine*, vol. 14, no. 2, p. 35, April 2016. The issue says courtesy of Siemens.)

Shunt applications FACTS (static compensators and static var compensators) provide dynamic voltage support and improve network stability. Series applications are less common, but thyristor-controlled series compensators have been successfully used to stabilize systems and eliminate subsynchronous resonance. The future appears bright for new FACTS controllers as they become less expensive due to improvements in power electronics modules and the ability to connect directly to higher voltage systems. New types of devices creatively control the network, and some can limit short circuit availability.

Transmission Structures

Making better use of existing and new rights-of-way can reduce costs and facilitate the siting of transmission circuits. Traditionally, the replacement of existing transmission circuits with higher voltage facilities allowed for more power transfer over a given footprint. Recent trends show that converting long ac circuits to HVdc can be an economical solution. Several other emerging methods of achieving higher power transfers over limited rights-of-way include installing the following:

- compact structure designs, which can increase voltages and provide higher surge impedance levels and increased thermal capabilities
- new types of overhead conductors with increased ampacity
- underground cables that may be self-contained or even superconducting, which are environmentally friendly and easier to site
- dynamic line rating technologies, especially to integrate wind farms.

Transmission structures must meet environmental constraints. New means of harmoniously accommodating wildlife, especially birds that nest on towers, facilitate siting and reliable operation. Designs utilizing lower structures and high strength conductors decrease the spans per mile, which saves money and reduces adverse visual impacts.

Substation Equipment

Applications of the considerable advances in substation equipment make better use of available land and transmission facilities. New materials and innovative designs have reduced substation costs and negative environmental impacts. New gas-insulated substations no longer need to use only sulfur hexafluoride, which is a potent greenhouse gas. Performance monitoring can make better use of existing facilities and improve reliability, which is becoming increasingly important for an aging infrastructure. The use of new surge arrestor designs also helps to protects equipment, therefore extending its life.

Distribution Innovation

Advanced automation schemes, such as fault location, isolation, and service restoration (FLISR), are being deployed by utilities in distribution systems to improve reliability. Automation schemes such as FLISR are needed to cost-effectively improve reliability and are monitored and controlled in real time by supervisory control and data acquisition (SCADA) systems. Distribution automation can also provide support for the enablement of DERs by incorporating the visibility and flexibility needed for operations.

“Four quadrant” smart inverters associated with modern DER facilities, including energy storage installations, offer the potential for relatively low-cost voltage support and control of voltage fluctuations on the distribution system. However, more research, as well as associated standards, is needed to fully understand the impact on utility reactive power demands, especially as PV penetration increases. In addition, the lack of any business model to compensate DER owners for the added expense of the smart inverter may slow adoption.

There is a compelling need for more granular visibility and monitoring of distribution systems and DERs via the IoT. Consumer security and privacy are a continued design concern. There is a need for comprehensive modeling, simulation, and analysis tools and the incorporation of low-voltage distribution grids into standard distribution system models. It is vital to not only increase the real-time and near real-time monitoring of distribution systems (e.g., using GPS synchronized measurements) but also to have the ability to assess and prevent potential service disruptions and disturbances associated with DER operation.

Changing inertia and system impedance may drive more circuit breaker replacements and increase the need for adaptive protection and control schemes. Adaptations at the bulk power level will be required to replace inertial and governor response from conventional synchronous generators. Fast inverter-based resources, especially storage, can respond in just a few cycles and be used to respond autonomously to rate of change of frequency as a pseudo-inertia response and to frequency deviation with a droop to emulate speed governors. When coupled with high-speed communications and control and synchrophasor applications, their response could conceivably be coordinated system wide to enhance stability. However, new technical issues around distribution system grounding requirements, especially dealing with harmonics and other power quality issues caused by large inverters, may arise. This is more likely to become an issue for large industrial customers or in future microgrids.

The variability of short circuit availability (high and low) means adaptive control and protection designs become more important. In general, protection settings will have to be dynamically and automatically modified when operational conditions change, particularly with larger penetration levels of DERs. Dynamic modification is only possible with modern microprocessor-based relays. Advanced protection and control schemes should be evaluated for several scenarios such as the following:

- a change in operational conditions of a feeder such as generation and load changes including reverse power flow and back feeding
- a change in circuit topology according to the distribution automation scheme
- the ability to quickly clear the fault and restore customers
- fault detection and clearing in the grid-connected and islanded modes
- a tolerance to change in fault current capacity due to the presence of power electronic based DERs.

Solid-state voltage regulators and transformers are technologies that can help address changes in the grid due to the high penetration of DERs.

Energy Storage Innovation

Energy storage promises the ability to mitigate renewable DER variability and improve T&D utilization and economics. It is understood that “shared applications”—the multiple use of the same energy storage device—is key to realizing the best economic potential from the technology. Regulatory barriers and legacy paradigms have been addressed at some jurisdictions and need to be addressed at others to enable the adoption of these technologies and their most effective uses. Storage may not fit into one of the conventional categories (such as generation, load, T&D, consumer, and transportation) or follow established rules for that asset class. It is uniquely able to perform services across asset classes, such as the Battery Energy Storage System (BESS) facility in Tehachapi (Figure 4). Storage is potentially a new asset class of its own, but new regulatory regimens and market rules may be necessary.

Energy storage and other DER technologies capable of rapid response to control signals offer the promise of providing the capabilities to manage the variability of renewable DERs both locally on the distribution system and in the power system overall. However, mechanisms for effectively incorporating DERs in grid ancillary and balancing services have yet to be fully developed. The business models that make this attractive to the markets, utilities, and DER owners are still under debate.

Legacy planning and operations analytics and processes do not account for energy storage in general or suboptimally. This slows down utility adoption and understanding.

Figure 4. A monolith substation and BESS facility in Tehachapi, California. The BESS provides transmission services, system capacity, and ancillary services. (Source: Google Earth. Appeared in *IEEE Power & Energy Magazine*, vol. 15, no. 5, p. 56, Sept./Oct. 2017.)

Electrical Transportation Innovation

Electric transportation holds significant promise for reducing dependence on oil and our carbon footprint. Electrical transportation systems can help improve the livability, workability, and sustainability of "smart cities." Electrical transportation includes electric trains and electric vehicles (EVs) (cars, buses, and trucks) as well as enabling electrical corridors to transport people and goods.

Specifically addressing EVs, studies have shown that the first purchase of an EV is likely to inspire more in the same neighborhood, which can lead to the emergence of clusters and may overload the local distribution system transformers. Distribution system capacity upgrades, in combination with solutions based on DERs and intelligent load control, are able to counteract these overloads. Furthermore, while EV discharging back to the grid, commonly known as vehicle-to-grid, is still undesirable from an automotive original equipment manufacturer perspective due to the impact on battery life, there is still the potential for the EV to provide local backup power to the consumer. This could become both a selling point for advanced EV chargers, especially in conjunction with PV and household energy storage, and a new challenge for interconnection standards. This operational mode is not yet widely explored, and its impact on utility standards, interconnection, etc., remains uncertain (the nature of standards likely will be similar to backup generation or islanded PV operation).

Microgrid Innovation

Microgrids have existed for years on university campuses, military bases, and large industrial sites and at various critical infrastructure locations where combinations of the economics of Distributed Generation (DG) and demand response, the need for very high reliability, and research objectives all led to their development. Today, the microgrid concept is seen as an alternative to enhance resiliency, facilitate the DER integration, and provide efficient energy supply to isolated or remote areas.

Larger microgrids plan and implement sophisticated scheduling and control systems that can optimize their energy usage, production, and grid sales and purchases across the day. As microgrid systems become more integrated with smart buildings and smart charging systems for EVs, their flexibility and complexity will only grow. When a major campus, commercial park, or residential community seeks to establish a microgrid but does not own HV distribution, the utility must become a partner in its creation. This may include the engineering and planning, and potentially the ownership, of some of the control and interconnection systems. Pilot projects for this model exist worldwide, but business models implemented within tariff structures, as well as clear regulations regarding asset ownership, privacy, liability, etc., do not exist as yet. A microgrid architecture, with various deployment options, is shown in Figure 5.

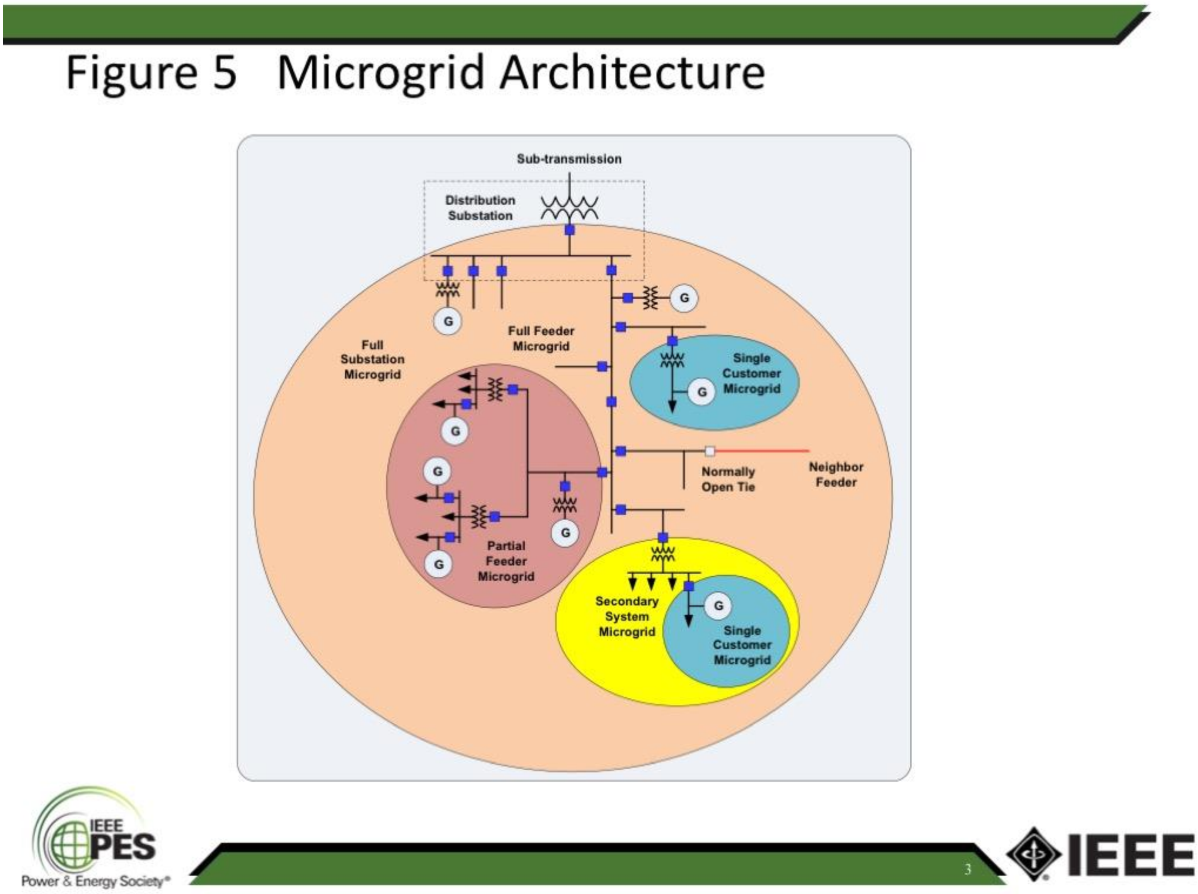

Figure 5. A grid-interactive microgrid architecture.

Integrating the Network

Some of the aspects of issues related to overall grid planning, operations, and maintenance are addressed next.

Integrated T&D Planning

For decades, the planning and operations of T&D systems were separate activities with little or no integration and interaction. The distribution planning engineers provided the forecasted bus loads to the transmission planners, and the distribution SCADA engineers might pass on bus load data to transmission. Transmission rarely provided information to distribution, as distribution planning and operations analytics always assumed that the transmission system was an infinite bus (i.e., fixed voltage) behind an equivalent impedance representing mainly the distribution substation transformer.

As the variability of distribution system net load increases, better coordination and information transfer is required. For example, the independent system operator (ISO) can no longer rely on simple load forecast bus allocation factors to forecast bus net loads but must be able to forecast PV production. More importantly, the use of DERs to provide aggregated energy supply to the T&D system and ancillary services to the wholesale markets will be increasingly valuable. Some of that information will flow back and forth via the distribution system operator (DSO), but some will also need to flow directly to bulk power system stakeholders. For example, the DSO may aggregate ancillary services provision by DERs, but the ISO will require direct visibility for some ancillary and reliability services such as regulation for both control purposes and performance calculations and settlements. Current thinking and planning for the DSO often still reflects that traditional T&D divide. However, in a future electric industry where high renewables and DER penetration are the norm, the transmission operator will be unable to optimize schedules and dispatch without considering the impacts on the distribution system, and vice versa. Integrated wholesale/distribution market operations will become a requirement.

Communications and IoT integration

Furthermore, the IoT promises low-cost ubiquitous communications to DERs, which would facilitate incorporating them in advanced market and operations processes. However, distribution systems are expected to have a high level of reliability, security, and availability, even in catastrophic situations, requiring upgrades to improve capacity and reliability with increased automation. Thus, addressing standards and cybersecurity concerns should remain a high priority along with tackling consumer privacy and data ownership implications, especially for DERs not owned and operated by utilities.

The DSO Model

The DSO, or the distribution system platform, model is becoming mainstream. Wholesale concepts of day-ahead, hourly, and real-time markets using locational pricing to manage congestion are guiding principles. Considerable theoretical work, as well as some rigorous cost-benefit studies, has been done on this model. The on-going Reforming the Energy Vision process in New York is seriously considering this approach. However, more work needs to be done to fully implement the model, including clear regulation and tools and monitoring devices.

Integrated Asset Management

Consistent with recommendations of the U.S. DOE Quadrennial Review (QER), the power industry is deploying new resources and technology to address the need for maintaining and upgrading the aging grid, grid hardening against weather-related issues (including geomagnetic disturbances), high levels of reliability, and preventing and recovering from physical and cyberthreats that have been growing at an alarming scale. All of the above should be viewed in the context of holistic asset management. A holistic approach in support of business goals includes the management of an aging infrastructure (including condition monitoring and assessment tools), grid hardening (weather-related response, physical vulnerability, and cybersecurity), and system capabilities (including reliability improvements). The entire equipment fleet must be managed to achieve system reliability and meet customer service needs through effective planning and operations.

What Is the Future of the Grid?

The pace of the electrical power system delivery change depends on multiple factors. The vision could be summarized as follows:

- The need for electricity will increase with continued improvements in energy efficiency.
    - The population and need for reliable electrical energy will continue to grow.
    - Electrical transportation will proliferate in the form of electric trains and EVs (cars, buses, and trucks).
    - The key for fuel transformation is with renewable energy resources.
- Consumers expect a more resilient, safe, reliable, and efficient grid that requires advancements in technology and processes to be modernized.
- There is a need for clear and balanced regulatory policies, e.g., removing barriers to combine reliability and market applications of DERs and storage.
- The value of electricity will be seen as more than just a commodity.
    - Consumers will require more choices, digital-age reliability, and comfort and value.
    - It is the cornerstone for societal and economic goals to meet sustainability needs and support a growing economy.
- T&D systems will continue changing while providing pathways for the transportation of clean energy between production and consumption centers while fortifying electric system efficiency, stability, and supply reliability.

The keys to a smarter grid are an educated workforce, developing and applying standards, and sharing global best practices. All of this is what IEEE provides to the industry and society.

IEEE Does the Job

In this fast-paced environment, standards are more critical for both users and vendors to streamline the deployment of both existing and new technologies and support interoperability among devices and systems as well as the use of best industry practices. The IEEE, in coordination with the National Institute of Science and Technology and the DOE, has sponsored numerous committees, working groups, and standards to address the needs of the electric power industry pertaining to DG integration. Arguably the most prominent efforts are embodied by the IEEE 1547 series of interconnection standards, a group of standards, guidelines, and recommended practices that cover a comprehensive set of aspects pertaining to DG integration. IEEE 1547, *Standard for Interconnecting Distributed Resources with Electric Power Systems*, is a key industry reference in this area. The QER has emphasized that the “DOE should work with industry, the Institute of Electrical and Electronics Engineers, state officials, and other interested parties to identify additional efforts the Federal Government can take to better promote open standards that enhance connectivity and interoperability on the electric grid.”

Grid modernizing requires a well-trained workforce, capable of dealing with the changes. IEEE offers a plethora of educational activities, including tutorials and webinars on emerging topics and standards in support of workforce development. As there is also a need for online simulation training tools, the IEEE Power & Energy Society is working on developing an open source platform through its Next Generation Energy Educational Initiative.

Furthermore, the IEEE Power & Energy Society disseminates the latest knowledge through

- its two award-winning magazines, a Spanish version of IEEE Power & Energy Magazine, transactions, and an open-access journal
- organizing 40+ industry-focused conferences and workshops globally every year, addressing emerging topics and industry standards
- developing standards, guides, and reports by 17 technical and three coordinating committees.

Biographies

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For Further Reading

- J.R. Agüero, E. Takayesu, D. Novosel, and R. Masiello, “Modernizing the grid: Challenges and opportunities for a sustainable future,” *IEEE Power & Energy Magazine*, vol. 14, pp. 74–83, May/June 2017.
- D. Tan and D. Novosel, “Energy challenge, power electronics & systems (PEAS) technology and grid modernization,” *CPSS Transactions on Power Electronics and Applications*, vol. 2, no. 1, Mar. 2017. <AU: please supply page numbers>
- IEEE Quadrennial Energy Review Report to DOE (2015, Sept.). [Online] Available: http://www.ieee-pes.org/qer