Quadrennial Technology Review 2015

Chapter 3: Enabling Modernization of the Electric Power System

Technology Assessments

Cyber and Physical Security

Designs, Architectures, and Concepts

Electric Energy Storage

Flexible and Distributed Energy Resources

Measurements, Communications, and Controls

Transmission and Distribution Components

U.S. DEPARTMENT OF
ENERGY

Quadrennial Technology Review 2015

Flexible and Distributed Energy Resources

Chapter 3: Technology Assessments

Introduction

The U.S. electric power system is undergoing significant changes. The reliance on large thermal generators of the past is giving way to a much more dynamic paradigm. In recent years, many new technologies have been connected to the traditional grid, including variable wind generators, plug-in electric vehicles, photovoltaic systems, fuel cells, microturbines, demand response and load modifying resources, and energy storage systems. This white paper examines the state of these technologies that reside at the "edges" of the grid—including flexible bulk generation and customer-sited distributed resources—that can be advanced to provide increased system flexibility.

Emerging professional standards, such as the Institute of Electrical and Electronic Engineers (IEEE) Standard for Interconnecting Distributed Resources with Electric Power Systems (IEEE 1547), are defining the requirements that these technologies must meet in order to safely and reliably interconnect. These standards address issues (such as low voltage ride-through, harmonic injection, and volt/VAR control) to ensure that new technologies do not jeopardize the safety or reliability of the electric power system. Strategic integration of clean energy technologies and distributed energy resources (DERs) not only requires interconnection but also maximizes the benefit these technologies and resources can provide to society while supporting secure and reliable electric power system operations.

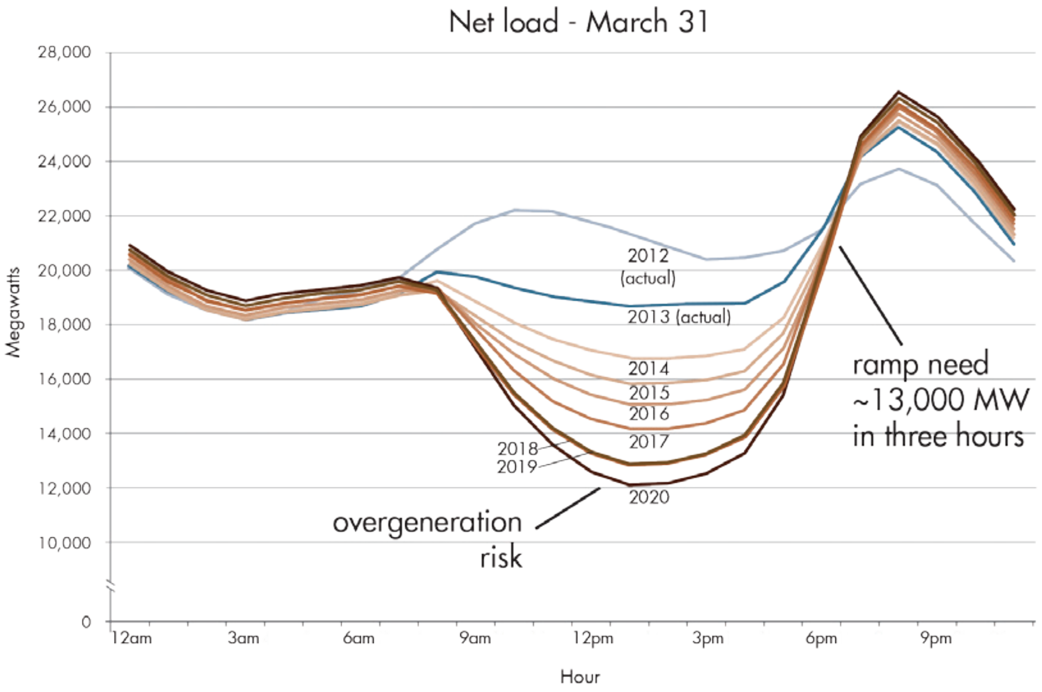
As more variable and distributed technologies continue to connect to the grid, the current system will have to evolve with the changing energy environment. For example, the California Independent System Operator (CAISO) conducted a study to demonstrate how the electrical system is likely to evolve as more renewable resources, especially solar photovoltaic (PV), take part in generation. As depicted in the CAISO "Duck Chart" in Figure 3.D.1, solar generation peaks around midday on a typical spring day at a time when demand is generally at low levels. Because conventional resources need to operate at a minimum level of output to be available for rapid ramping to meet evening peak load levels, there can be excess generation during this time.

As illustrated in Figure 3.D.1, the ramp rate needed to meet load becomes steeper by 2020, adding to the "overgeneration" challenge and greater demand for more flexible resources.

Similar to solar energy production, wind energy production also presents unique challenges to managing variability. Wind output is variable at all temporal scales—seasonal, weekly, hourly, and minute-by-minute—and can vary significantly within a geographical region and across co-located wind turbines. Figure 3.D.2 illustrates the impact that a representative wind power generation profile may have on the overall generation required to match a net power demand curve (net load). Integrating variable wind generation will require additional reserves or more flexible resources that can rapidly respond to balance the system. Options include load shedding and the use of other DERs.

Figure 3.D.1 CAISO Modeled Net Load Curve[1]

Credit: California Independent System Operator Corporation



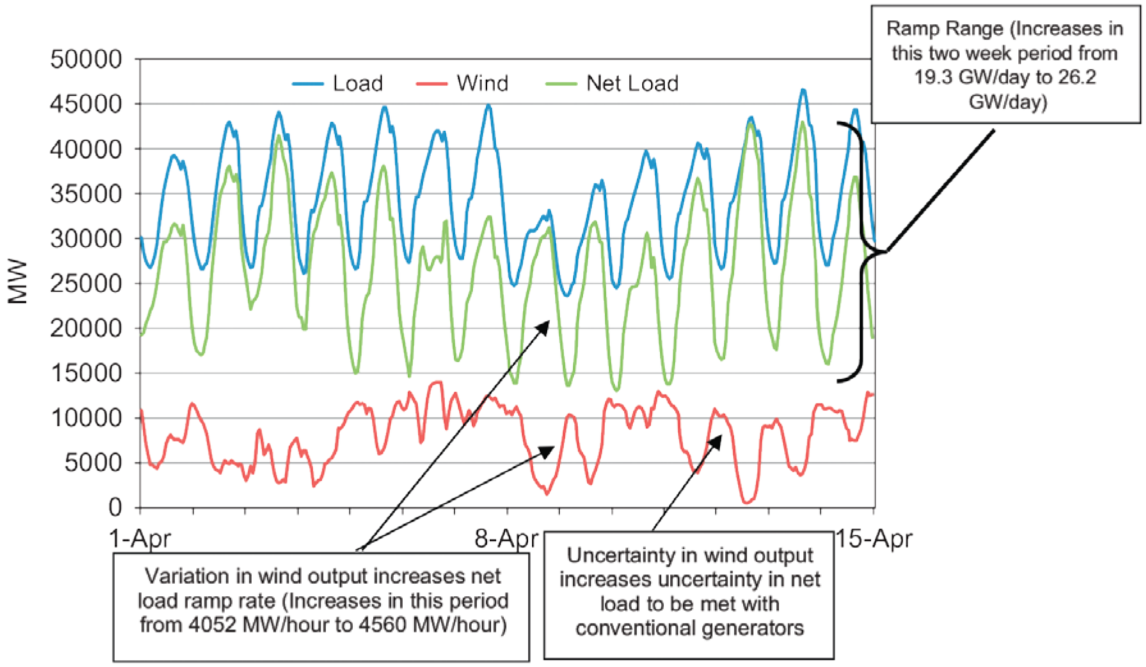
Net load - March 31

ramp need ~13,000 MW in three hours

overgeneration risk

Figure 3.D.2 System Load, Wind Generation, and Net Load for a Two-week Period in April

Credit: National Renewable Energy Laboratory



Ramp Range (Increases in this two week period from 19.3 GW/day to 26.2 GW/day)

Variation in wind output increases net load ramp rate (Increases in this period from 4052 MW/hour to 4560 MW/hour)

Uncertainty in wind output increases uncertainty in net load to be met with conventional generators

The Figure 3.D.2 plot uses Electric Reliability Council of Texas grid data from 2005, along with 15 GW of spatially diverse simulated wind data from the same year.[2]

Determining the value of DERs is an area of significant activity. Resource planners are working to understand the locational and system benefits (considering impacts to transmission, distribution, and generation) and associated costs of integrating variable and distributed energy technologies. Currently, there is no industry-accepted method for calculating the impact of these resources on traditional distribution equipment and operating schemes or the broader bulk power system. Efforts are underway in California, New York, and other states to develop such a framework. For the first time, California is requiring its investor-owned utilities to file distribution resource plans that are meant to present a consistent methodology for utilities to value the locational and system benefits of distributed resources. The More Than Smart initiative in California continues to provide a forum for a number of stakeholders to actively participate in this process. Within the New York Reforming the Energy Vision process, there is a plan to define a benefit-cost analysis framework to quantify the value of integrating distributed resources into the grid. As these frameworks continue to develop, system planners will likely need to conduct a thorough inventory and analysis of all the cost-effective energy efficiency, load modifying, storage, and flexible generation resources that can avoid costlier investments in infrastructure.

Generally, the integration of energy technologies into the electric power system can be separated into three tiers: the customer level, the community level, and the regional level. These three tiers are interconnected and interdependent as indicated in Figure 3.D.3. A holistic systems approach will be required to ensure that various energy technologies can be integrated in a safe, reliable, cost-effective, secure, and resilient manner. This systems approach will also require development and adoption of standards for cybersecurity and interoperability with the grid. By leveraging advances in individual devices, control methodologies, and telecommunication infrastructure, emerging technologies can be utilized to provide greater system flexibility. Technology solutions within each tier can be characterized by the spatial and power scales across the system for which they can provide energy and grid services.

Figure 3.D.3 Different Spatial Scales of the Electric Power System[3]

Credit: National Renewable Energy Laboratory

Technology solutions can be applied within each of the tiers to manage the dynamic phenomena associated with net and instantaneous electricity demand. This white paper looks specifically at customer-sited resources, integrated and aggregated resources, and bulk or modular flexible power generation options to help manage the growing variability and uncertainty of the evolving system. Market designs, policies, and regulation will influence the ability to aggregate DERs for the provision of grid services, presenting another dimension of challenges that are outside the scope of this paper.

Grid-Enabled Customer Resources

Grid-enabled customer resources are individual technologies that generally connect at the customer site (e.g., within a building, campus, or industrial manufacturing plant), reside downstream of a utility meter, and can be used to provide services to the grid. These technologies can be characterized as enhancements made to discrete loads and distributed generation to enable connectivity with and responsiveness to grid operations. Customer-level technologies are typically optimized for their primary function (such as lighting, heating, cooling, ventilation, pumping, electric generation, or electric vehicle charging) and operate at the discretion of the owner. Development of "smart" devices focuses on embedding local intelligence, communications, and control capabilities, which may be addressable by a utility or third party or be fully autonomous.[4] Ensuring cyber security, interoperability, and proper characterization and modeling of these various technologies will be critical for their use in advanced grid operating paradigms.

Additionally, communication network requirements (e.g., latency, architecture, bandwidth, and costs) and their impact on the stability and reliability of distribution system operation will require research and improved understanding to implement large amounts of grid-enabled customer resources. Demand response operations over existing communication systems, along with the interactions between the various distributed resources (autonomous or controlled), can result in complex coupled cyber-physical phenomena. Developing methods and technologies that utilize consumer IP networks, while ensuring system reliability and addressing security concerns, will be challenging. Alternatively, utilities could construct secure communication systems similar to existing advanced metering infrastructure (AMI) networks, but the greater capacity, bandwidth, and reduced latency will result in high costs.

Smart Loads

Demand response is a broad term for strategies used by utilities to shift electric energy consumption patterns, reduce total peak demand, or reduce total consumption (efficiency). It also includes demand dispatch, where increase in load is encouraged during times of excess generation.[5] Various demand response programs have been developed and deployed historically; they all generally focus on offering financial incentives for voluntary or direct control of loads in a binary fashion. As the electric power system becomes more dynamic and distribution systems become more complex, there has been a migration toward using decentralized control paradigms and distributed approaches for the provision of additional grid services.

Smart loads may include building or industrial control systems that are optimized for individual services (such as lighting, heating, cooling, ventilation, pumping, and processing) but can also interact with utility or operator signals. With the cost reductions in information and communication technologies, there are many opportunities to make a variety of loads more "grid friendly." The U.S. Department of Energy (DOE) demonstrated that a smart controller can be used with appliances to provide frequency response and load shifting autonomously.[6] Additionally, the industry trend toward Web-based systems, also often referred to as the Internet of Things, where many appliances and building systems are expected to be fully Web enabled, will allow many loads the opportunity to provide grid services if control capabilities are in place.

Challenges remain with ensuring that these loads will be capable of providing grid services without jeopardizing the quality and reliability of their primary function. For example, heating, ventilation, and air conditioning (HVAC) systems can be used to provide grid services such as regulation, but concerns that rapid cycling of the motors will degrade the equipment lifetimes will need to be addressed. While this degradation issue can be partially addressed through the deployment of variable frequency drives (VFDs), it remains an area of concern. In general, VFDs and other power electronics can also be utilized to provide grid services, such as reactive power support, and may be well suited to mitigate fault-induced delayed voltage recovery for the broader system.

Thermal energy storage systems (hot and cold) have been useful for conventional demand response programs such as load shifting. Thermal-adsorption loops have been developed to produce and store chilled water during off-peak hours for use with building and campus cooling/HVAC systems to reduce daytime air conditioning loads. Electric water heaters have also emerged as another form of thermal energy storage that can serve as a flexible resource. Grid-interactive water heaters or grid-interactive electric thermal storage allow for highly responsive control, including load shifting and frequency regulation.[7] However, this technology is facing challenges with meeting energy efficiency standards that will diminish the useful capacity it can provide for grid services. This issue is not unique for electric water heaters; other smart load technologies will require careful consideration of how efficiency will need to be optimized with flexibility.

There are many developing dynamic load management technologies on the customer side of the meter that will also play increasingly sophisticated roles in helping to manage the future grid. Advanced power electronics integrated into loads (e.g., consumer electronics) can provide enhanced control capabilities, including the ability to manage loads at the sub-minute interval. One example of these technologies is an electrolyzer for hydrogen generation, which can provide real-time grid services. As with other electric loads, the ability to quickly drop demand is equivalent to “up-regulation,” and a quick increase in demand would be equivalent to “down-regulation.”[8]

Smart Distributed Generation

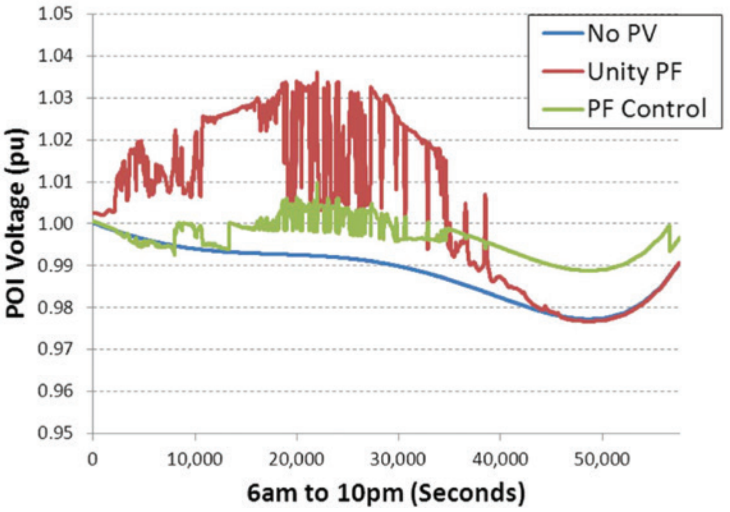
Current interconnection standards require distributed generation to disconnect when system voltage or frequency deviates from normal parameters in order to protect power system equipment and ensure the safety of line workers. These abnormal voltage and frequency conditions typically occur when contingency reserves are actually needed, such as when a large generator is tripped or a transmission line is disconnected. At these times, the loss of significant distributed generation can actually exacerbate the initial problem. To prevent contributing to system instability during a disturbance, distributed generation technologies will require enhanced functionality and need to meet new operational requirements.

With the significant penetration of solar PV expected in the near future, the capability to “ride through” local system disturbance while still disconnecting when appropriate will be important for grid friendly operations. The need for such changes is already emerging for some utilities. The Puerto Rico Electric Power Authority recently established minimum technical requirements for interconnecting wind and solar PV power plants that include voltage ride-through requirements, frequency regulation, and ramp rate control.[9] Hawaiian Electric Company similarly mandates renewable generators to comply with their performance standards, which address voltage regulation, reactive power capability, over/under voltage and frequency ride-through capabilities, and ramp rate control.[10]

Recent advances in smart inverter technologies enable PV systems to autonomously provide power factor correction to mitigate some of the variability presented to the grid at the point of interconnection (POI), as shown in Figure 3.D.4. Volt/VAR control (or power factor control) has been shown to mitigate voltage fluctuations and over/under voltage issues caused by the injection of power from solar generation. This is achieved by allowing the inverter to produce or consume reactive power (VAR) when needed instead of just producing real power. While this capability is technically feasible, there are two issues that need to be resolved for broad implementation. Historically, reactive power is not measured at the POI and is generally supplied or consumed by the local utility. Many utilities and stakeholders do not know how to value these new capabilities, limiting incentives for adoption. Secondly, the provision or consumption of reactive power requires excess capacity to be available on the inverter. Meeting this requirement is becoming more of a problem as the DC/AC power ratio for inverter designs is becoming greater than one, thus not allowing for reactive power flows without curtailing energy production.

Figure 3.D.4 Power Factor (PF) Control with a Smart Inverter[12]

Credit: Reigh Walling, GE Energy Consulting



Smart inverters can also provide other capabilities, such as voltage support, but may require embedded communications and local intelligence to ensure that these functions are coordinated with distribution system operations and enabled only when appropriate to do so. Recent amendments to IEEE 1547 embrace these changes by allowing distributed resources, such as rooftop PV with smart inverters, to actively participate in regulation of voltage and providing frequency response.[11]

Similar to solar PV with smart inverters, other distributed generation resources (such as backup diesel generators, combined heat and power [CHP] systems, and fuel cells) can be enabled to provide automated or coordinated control to support grid conditions. This enhanced capability will need to be designed into these technologies to ensure it can optimize between maximizing the generation of electricity and the provision of grid services. Additionally, the availability of smart distributed generation technologies will be important for advanced applications, such as microgrids, that are resilient to system outages.

Smart Electric Vehicles

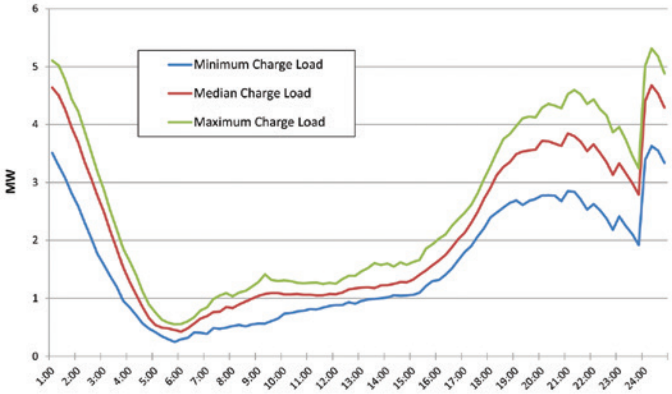
The projected increase in deployment of electric vehicles presents a unique challenge and opportunity for the grid. Without specific time-of-use customer feedback and timed charging capabilities in place, these mobile "batteries" can result in very large system loads (level 3 charging) that can add significant costs to the grid. Figure 3.D.5 illustrates the potential issue with unmanaged electric vehicle charging; the charging profile peak tends to be coincident with the evening system peak when customers return home from work. It is expected that as more electric vehicles are deployed, evening charging habits of electric vehicle owners will push up system peaks. Development of smart electric vehicle supply equipment can enable electric vehicles to participate in utility demand response programs or other load management schemes to support grid operations and mitigate the growth in system peaks. Other technology options being pursued include embedding communication and control capabilities in the electric vehicles themselves to provide grid services. As with other smart loads, research is needed to ensure that the primary function of the technology—reliable transportation on demand—can be optimized with the provision of grid services.

The concept of vehicle-to-grid enables an electric vehicle to put power back onto the grid, providing the power system with an extra degree of flexibility. Instead of simply being a smart load, this capability allows electric vehicles to act like an energy source (especially a plug-in hybrid electric vehicle), supplying grid services as a grid-connected battery, including one that can provide mobile backup power during an outage or emergency situation. This capability will require the development of vehicle power electronic systems with bidirectional flow, integrated communications, and improved battery management systems. Estimates indicate that vehicles are only used 5% of the time for active transport; therefore, the vehicle battery could be made available to provide a range of grid services.[15] Unique challenges include original equipment manufacturer concerns with the impact the provision of these services will have on battery life and the quality of their product. Owners'

Figure 3.D.5 Electric Vehicle Charger Level (left) and Typical Charging Profile (right)[13, 14]

Credit: Pacific Northwest National Laboratory

Charger Level	Lead	Charge Time	Voltage in Alternating Current (VAC)
Level 1 (Home)	1.1-1.8kW	6-10 hours	120
Level 2 (Home & Work)	3.3kW	3-4 hours	208/240
Level 2+ (Home & Work)	6.6-19.2kW	30 mins-2 hours	208/240
Level 3 (Recharging Station)	50-150kW	15-30 mins	480



concerns with having a utility or third party controlling their property are another obstacle. Batteries that do reach the end of their usable life in an automotive application can, however, retain significant value in a second life as a grid storage resource.[16,17]

Integrated and Aggregated Resources

Integrated and aggregated resources are technologies consisting of multiple grid-enabled customer resources that operate as a single group. These technologies are characterized by coordination of and optimization between various individual distributed technologies, through advanced measurement, communications, modeling, and controls, that provide energy and grid services upstream of a utility meter. Such community-level technologies require close coordination with distribution management systems (DMSs) and knowledge of distribution system configurations and topologies. These technologies will also require much tighter integration between transmission energy management systems and DMSs so that operations of distributed resources can be coordinated to serve needs at both levels when possible and to resolve any conflicts.

Broad deployments of AMI and the potential of dynamic pricing or other control signals (e.g., transactive) are creating an opportunity for the meter, as well as the Web, to serve as a platform to engage with customers and customer assets. Development of technologies that can perform multi-objective optimization, meeting customer demands as well as power system needs, will facilitate the interaction and engagement with customers. However, the complexity of interactions among and across the various technologies, the diversity of customers, and the broader distribution system present unique challenges.

In addition to ensuring cybersecurity, interoperability, and proper characterization and modeling of the various individual technologies, these technologies can also be integrated or aggregated. Key challenges associated with integration and aggregation include the following:

- Understanding the impact on distribution assets and legacy components
- Gaining visibility into distribution system power flows
- Coordinating and developing new adaptable protection schemes
- Establishing a common framework to evaluate resource capabilities

- Integrating and optimizing different distributed resources, including storage
- Aggregating and coordinating geographically dispersed resources
- Managing and coordinating many more (millions to billions) control points
- Coordinating with distribution and bulk system operations (energy management systems)

Smart Buildings

Buildings consume 70% of total electricity generated and 50% of total natural gas production in the United States.[18] This fact presents opportunities for increasing energy efficiency, meeting customer needs and comfort levels, and supporting grid operations simultaneously. The potential to take advantage of the thermal inertia in buildings and flexibility in the timing of energy uses to enhance power system operations is quite significant.[19,20,21] Residential and commercial buildings, as well as industrial plants, consist of many physical assets that can be considered an energy ecosystem. From power sources (e.g., distributed generation, including CHP systems), loads (e.g., appliances and machines), and storage (e.g., batteries and thermal energy) to controls (e.g., building energy management systems), buildings and industrial plants can have all the components that form an integrated electric power system.[22] However, communication and control capabilities among these various assets and technologies do not exist or they are not standardized across different vendors.

Development of sensors, communications, and controls that can integrate building assets or industrial equipment can provide needed flexibility for the grid. These capabilities will allow building and plant owners and operators to optimize their systems to meet various objectives, such as reducing energy costs, maintaining resident comfort, maximizing industrial production, and providing grid services. Remaining challenges include establishing interoperability standards, improving the fundamental understanding of buildings and industrial plants as an integrated system, and developing design tools to help owners make better investment decisions. Additionally, homes and small-to-medium commercial buildings generally lack supervisory control systems (e.g., home energy management or building management systems) that can interact with utility signals for the provision of grid services. Innovations in the development of these systems, including applications such as forecasting for demand response and diagnostics for optimization and energy efficiency purposes, will be needed.

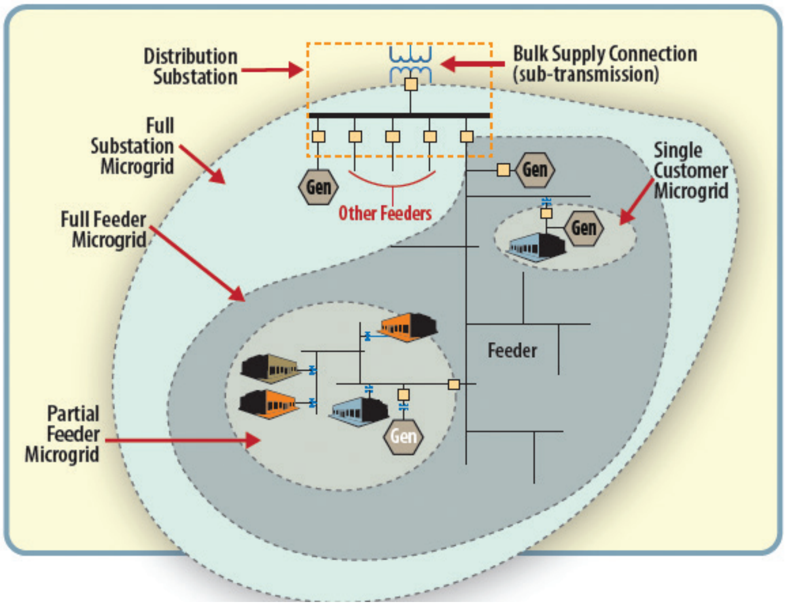
Microgrids

According to the DOE Microgrid Exchange Group, “a microgrid is a group of interconnected loads and DERs within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. It can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.”[23] Since the concept of a microgrid can be nested, one within another, as shown in Figure 3.D.6, a naming convention according to their configuration is used to differentiate them. A single-customer microgrid is the smallest unit and is generally characterized as being behind a utility meter. A smart building that can connect and disconnect from the distribution system and operate in island mode would also be considered to be a single-customer microgrid. Microgrids currently deployed are generally buildings with on-site generation, such as hospitals and data centers, or large campuses, such as universities or military bases. Large industrial facilities with on-site generation inherent in the plant’s process can also become microgrids (e.g., paper mills and refineries). The concept of the microgrid is rapidly evolving beyond back-up power to include islanding capabilities for critical infrastructure and the management of DERs (e.g., batteries, renewables, and electric vehicles) in conjunction with building or industrial loads.

Most microgrids operating today are single-customer microgrids and focus on integrating traditional generation resources (e.g., CHP and diesel generators) with new technologies such as renewable generation and electric energy storage systems. Customized communication and control technologies were developed to enable these resources to act as a single entity with respect to the grid. Operating and control algorithms can be developed to optimize one or more objectives characterized as follows:

Figure 3.D.6 Alternative Microgrid Configurations

Credit: Sandia National Laboratories



- Reliability—the microgrid serves as a grid resource in grid-connected mode and switches to island mode on detecting a contingency, thus improving reliability metrics.
- Security—the microgrid ensures that critical loads can be served for sustained periods of time during catastrophic events such as hurricanes or attacks.
- Economic—the microgrid responds to real-time changes in electricity prices to minimize total energy costs, choosing to decrease loads, increase self-generation, or charge batteries.
- Environment—the microgrid operates in a manner to maximize electricity produced from renewable resources to reduce overall emissions.

DOE has developed a number of microgrids through the Smart Grid Demonstration Program and the Smart Power Infrastructure Demonstration for Energy Reliability and Security program[24, 25] Alternative performance levels were tested, and various benefit streams were demonstrated. However, microgrids still face a number of deployment challenges, including high costs, regulatory barriers, and limited experience with the technology. The total cost to build and run a microgrid includes capital, operation, maintenance, and fuel.

According to the Green Energy Corp database, the average microgrid installation costs roughly $4.7 million per MW of capacity.[26] This price is not competitive with other technology options, but recent extreme weather events (e.g., Hurricane Sandy) highlighted the value of microgrids for energy security. Currently, many states and local communities are interested in developing microgrids to increase security and resilience and to meet other community objectives. In addition to high costs, utilities have been reluctant to invest in and incorporate this technology due to the lack of experience operating and controlling microgrids in coordination with the larger grid. Uncertainty about the regulatory structure and revenue model under which microgrids would operate is another challenge. Several utilities are currently engaged in developing microgrid controllers and systems, including collaborative efforts with the Electric Power Research Institute. System architectures, optimization algorithms, modeling and analysis, design tools, standards, and regulatory policies are needed to advance the state of microgrids. Other technical opportunities include developing more complex controllers, exploring the benefits of DC microgrid designs, and coordinating nested and networked microgrids[27] with each other and with other DERs.

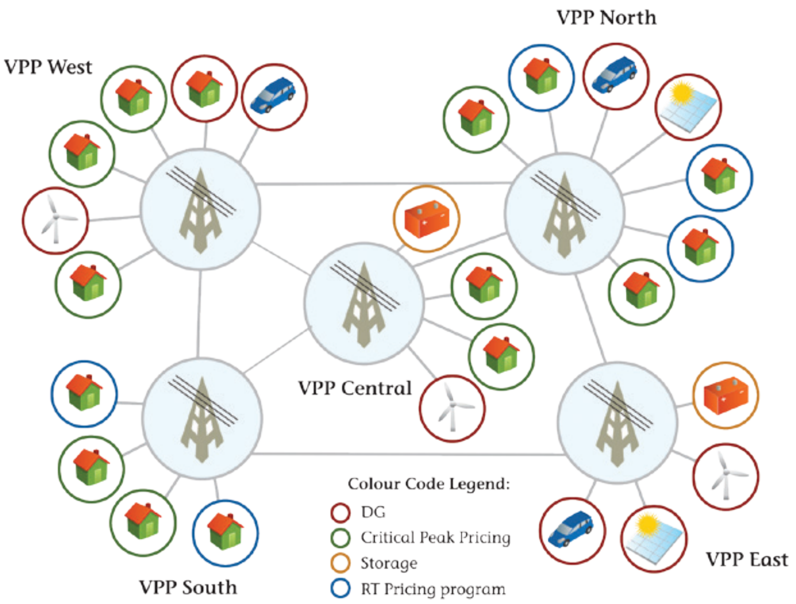
The federal government can play an important role in helping this technology overcome barriers by bringing together stakeholders to address the various issues. Examples include development of the IEEE 2030 standard for microgrid controllers to provide guidance of what constitutes microgrid supervisory controls and applications and the Performance Excellence in Electricity Renewal standard that supports building business cases around hardened and more resilient power systems.

Virtual Power Plants

A virtual power plant is an operating concept where a group of DERs that are geographically disperse (e.g., associated with different utility meters, residing on different feeders, or not having clearly defined electrical boundaries) is aggregated and coordinated to act as a single entity. This technology concept can include any combination of individual grid-enabled customer resources (e.g., distributed generation, electric vehicles, and energy storage) or integrated resources (e.g., smart buildings and microgrids). Additionally, the control of the aggregated resources is accomplished through a mix of strategies and signals that can involve markets. The concept of virtual power plants is shown in Figure 3.D.7.

Figure 3.D.7 Portrayal of Virtual Power Plants (VPPs)[28]

Credit: Ventyx



Key: **DG** = distributed generation; **RT** = real time

Major challenges to implementing this technology effectively include the need for good understanding of the physical topology and connectivity of the various systems where the resources are located and broad visibility to observe the state of various components and assets. A software platform, such as a Distributed Energy Resource Management System (DERMS), could be used to implement this concept.[29] If the DERMS is well integrated and interoperable with various utility DMSs, then it is possible to use virtual power plants to optimize distribution system conditions and to aggregate various distributed resources to provide services to the bulk transmission system. Advances in communication, modeling, and controls are needed to more broadly utilize this technology.

Aggregated demand response is a subset of this concept. There are a growing number of companies that use advances in communication and control equipment to enable various disperse loads to act as a single entity through software platforms. The aggregated resource can bid into wholesale electricity markets and provide other grid services if allowed. Integrated and aggregated resources can have special value in situations where conventional flexible resources are more difficult to use for a variety of reasons, including barriers to building new generation in densely populated areas and in areas with air pollution limits. In these situations, a combination of coordinated loads, distributed generation, storage, and other technologies can be more easily deployed to meet system needs. Additionally, by combining geographically disperse resources, correlations between resources can be decreased, which enables greater flexibility and decreases uncertainty associated with individual resources if operated in isolation.

Flexible Bulk Generation

Flexible bulk generation refers to technologies and enhancements to generation systems that connect directly to the bulk transmission system and are generally referred to as resources with “fast ramp” capabilities. These include aero-derivative turbines, gas-fired internal combustion engines, and certain storage facilities. These regional level technologies are characterized by advances in system designs and operations, upstream of a generator substation, to increase overall performance and flexibility to support grid operations. Advances in these technologies will require material and design innovations, secure communications, improved control capabilities, and the integration of various technologies. Ensuring cyber security, interoperability, and proper characterization and modeling of these various technologies will also be critical for their use in grid operations.

As more variable renewable generation (e.g., wind and solar) is deployed on the system, economic dispatch of conventional thermal generation will be significantly impacted, requiring generators to ramp and cycle significantly more to compensate for the increased variability. Figure 3.D.8 illustrates the degree of ramping and cycling in modeling results for generator dispatch under three different wind and solar penetration scenarios. Conventional thermal generation units were not necessarily designed for flexible operations, introducing inefficiencies and added stress to plant components as well as challenges to the economics of these units. Improved designs for both thermal and renewable units, fast ramp resources, and hybrid concepts (which include a combination of generators with thermal/electrical storage) can allow for optimization between electric output, costs, and flexibility. In addition, new developments in wind ride-through capabilities and the potential to combine solar thermal generators with enhanced thermal storage and solar PV with electric storage systems have the potential to help mitigate the increased need for flexibility in the system.

Plant Optimization

Industry is responding to the challenges of increased thermal ramping and cycling with innovations in operational procedures, control systems, advanced materials, and new designs. Rapid ramping and cycling increase wear and tear, resulting in reduced equipment lifetime and increased maintenance costs. Modeling suggests operating and maintenance cost would increase by 2% to 5%,[31] providing a business case to identify solutions.[32] Other than developing operational procedures to minimize stresses on current thermal units, deployment of new sensors and improved control systems allows for optimization that can increase component lifetimes, enhance flexibility, and increase generation efficiency.

The private sector has begun looking at some of these technology options as well as focusing on new combined cycle plants designed for fast response (~35 MW/min) and high efficiency (~60% net thermal). Many of the major turbine manufacturers, for example, have also introduced new generation systems with an emphasis on flexibility and featuring upgrades such as better internal controls, enhanced components, and new architectures.[33] One example of a fast-start design is at the Lodi Energy Center. Installed is a 300 MW base load generation facility capable of ramping to full load within 30 minutes, as illustrated in Figure 3.D.9.[34] Another example is an advanced control system that allows wind turbines to provide primary frequency response to support grid operations.[35] DOE is currently pursuing a number of advanced technologies for thermal units aimed at improving operational efficiency to mitigate carbon emissions, which may also be used to increase flexibility.

Hybrid Systems

Hybrid systems are a concept similar to the integration and aggregation of DERs, but for bulk generation. Hybrid systems offer opportunities for improvements in plant efficiency and flexibility but also require much more sophisticated controls and improved sensor systems to provide critical process information in a timely and reliable fashion. In many cases, this will require advances in sensor technologies to handle extreme operational conditions (e.g., high temperatures, high pressures, and corrosive and erosive environments). While the application of advanced sensors and controls in an individual plant can increase efficiency and provide

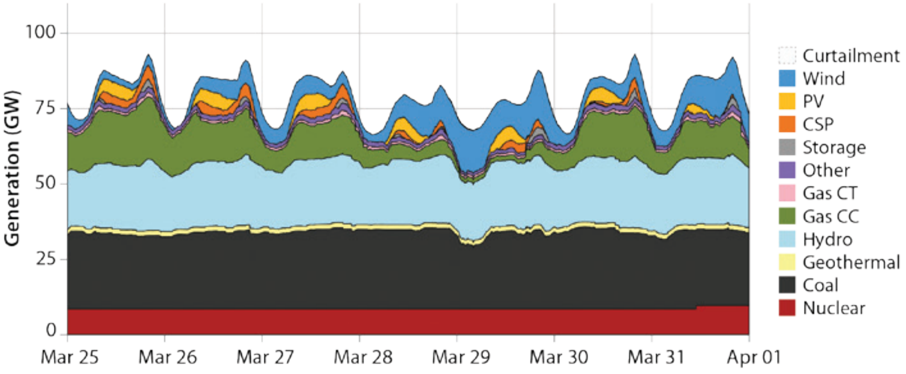
Figure 3.D.8 Western Electric Coordinating Council Generator Dispatch in 2020 for Various Scenarios[30]

Credit: National Renewable Energy Laboratory

Transmission Expansion Planning Policy Commission Scenario

9.4% wind

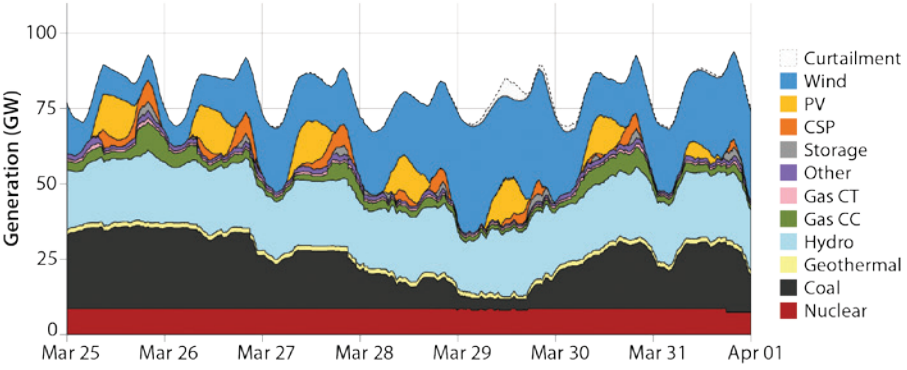
3.6% solar



High Wind Scenario

25% wind

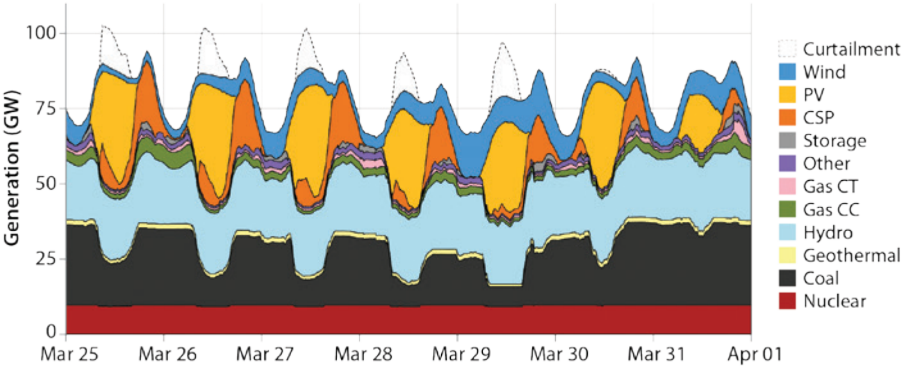
8% solar



High Solar Scenario

25% solar

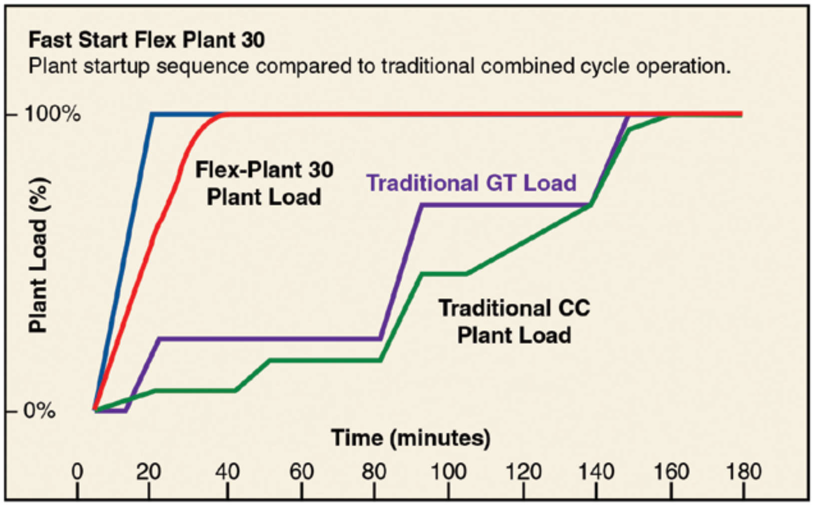
8% wind



new capabilities, a hybrid system offers significantly more flexibility in optimization across various objectives (within a single plant or across geographically dispersed plants). For example, combining a conventional thermal generator with a battery will allow the system to meet ramping requirements without substantially degrading the operational efficiency of the thermal unit or increasing wear and tear. The thermal unit can keep the battery at the desired state of charge, simplifying operational considerations. DOE has been conducting research on understanding the systems integration, controls, and coupling of thermal generators with other technologies.[37]

Figure 3.D.9 Comparison of Ramping Capabilities for Various Thermal Generators[36]

Credit: Isles, Junior. "Lodi's 300MW Flex 30 plant ushers in a new era for the US." Gas Turbine World, September - October 2012.



Blue Trace is an "ideal" ramp.

In the most general sense, a hybrid energy system provides dynamic use of thermal and electrical energy on an industrial scale. To realize the value of providing the grid with a single highly responsive dynamic system, coupling of all subsystems is necessary "behind" a single electrical transmission bus (grid interconnection). On a plant level, material and energy flows are integrated to optimize use of energy sources based on quality, price, and environmental attributes. An important feature of this type of integrated energy system is that it can produce multiple products based on instantaneous demand while increasing overall system reliability and maximizing profitability with efficient utilization of all capital-intensive assets. Hybrid systems could provide grid operators with an additional option for balancing the electric power system.

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Glossary and Acronyms

Advanced metering infrastructure (AMI)	An integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.
California Independent System Operator (CAISO)	California Independent System Operator. ISOs are independent organizations that are responsible for managing a regional transmission grid.
Demand response	A broad term for strategies used by utilities to shift electric energy consumption patterns, reduce total peak demand, or reduce total consumption.
Distributed energy resource management system (DERMS)	A software-based solution that increases an operator's real-time visibility into the status of distributed energy resources and allows distribution utilities to have the heightened level of control and flexibility necessary to more effectively manage the technical challenges posed by an increasingly distributed grid.
Distributed energy resources (DER)	Smaller power sources that can be aggregated to provide power necessary to meet regular demand.
DOE	U.S. Department of Energy
Electric vehicle supply equipment (EVSE)	The conductors, electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to an electric vehicle.
Fault- induced delayed voltage recovery (FIDVR)	A low -voltage condition initiated by a transmission or distribution fault that is characterized by initial voltage recovery to less than 90% of pre-contingency voltage, followed by slow voltage recovery, taking many seconds, to return to original level—often accompanied by an over-voltage condition.
Frequency	The oscillations of alternating current (AC) in an electric power circuit. It is measured in Hertz. The frequency of AC supply in the United States is 60 Hz.
Frequency ride -through	The capability of electrical devices to operate through periods of lower grid frequency
Internet of Things (IoT)	The network of physical objects (or "things") embedded with electronics, software, sensors, and connectivity that enables it to achieve greater value and service by exchanging data with operators and/or other connected devices. Each thing has a unique identifier in its embedded computing system but can interoperate within the existing Internet infrastructure.
Low voltage ride through (LVRT)	The capability of electrical devices to operate through periods of lower grid voltage.

Microgrid	A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. It can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.
Power factor correction	If an electrical current is not in phase with the applied voltage, the phase shift reduces the amount of the applied power usable in the circuit by a fraction known as the power factor. Power factor is the ratio of "actual" power (active power) being used in a circuit, expressed in watts or more commonly kilowatts (kW), to the power "apparently" being drawn from the mains, expressed in volt-ampere or more commonly kilo volt-ampere (kVA). By adding other components to the circuit, users can restore the power factor to a normal value and reduce or eliminate the adverse effect of the phase shift.
Reactive power	The component of an AC electric power that establishes and sustains the electric and magnetic fields in inductive and capacitive circuit elements. It is measured in VAR.
Real power	The component of an AC electric power that performs work (i.e., results in net energy transfer in one direction). It is measured in watts.
Regulation Services (up-regulation, down regulation)	Power sources online, on automatic generation control, that can respond rapidly to system-operator requests for up and down movements; used to track the minute-to minute fluctuations in system load and to correct for unintended fluctuations in generator output to comply with Control Performance Standards (CPSs) 1 and 2 of the North American Reliability Council (NERC 2002)
Volt/VAR control (VVC)	A fundamental operating requirement of all electric distribution systems. The prime purpose of VVC is to maintain acceptable voltage at all points along the distribution feeder under all loading conditions.
Voltage (instantaneous)	A measure of the electric potential difference between any two conductors or between a conductor and earth. It is measured in volts.