5. Optimize Grid Operations

1. Profile

Electricity networks are changing today in ways that fundamentally challenge traditional grid reliability and planning tools. New technologies and approaches are creating opportunities – but also challenges – that will require innovative approaches by electricity grid operators to meet system needs reliably and at least cost. These issues are of greatest interest to utilities, grid operators, and public utility commissions, but many also have greenhouse gas (GHG) emissions ramifications. This chapter focuses on approaches that have the most influence on GHG emissions, and summarizes emerging opportunities that can simultaneously improve electric reliability and reduce air pollution.

"Optimizing grid operations" refers to activities undertaken to improve the performance and efficiency of electricity transmission and distribution systems by grid operators (i.e., independent system operators [ISOs], regional transmission organizations [RTOs], and distribution utilities). Performance improvements include better and lower-cost levels of grid reliability, more efficient delivery of electricity, reduced system losses, and increased capacity utilization for more efficient use of assets (and thus requiring, over time, less capital investment). This chapter describes innovative approaches for the active management of the bulk electricity transmission and distribution systems to accomplish these improvements. It also covers enhancements to load management and rate design that can foster better management of the distribution system.

Optimizing the operation of transmission and distribution systems has not been a typical control measure considered by air quality agencies for GHGs or for other regulated air pollutants.[1] However, improved grid operations can help to reduce GHG emissions and improve air quality, and states that implement these options may be able to develop more cost-effective plans for reducing GHG emissions. Improved grid operations may also be a suitable option for regional (multistate) collaboration on emissions reductions because electricity grids are characteristically multistate in nature.

Efforts to optimize the grid system center on the many strategies that can be used to get the same or greater capability out of a utility's wires, saving energy and thereby reducing the need for upstream generation. Examples include optimizing voltage regulation and power factor management, adjusting load levels, and enhancing levels of grid intelligence to meet energy demands (e.g., "smart grid" solutions). Efforts to optimize grid operations can also include market mechanisms to encourage the participation of new service providers and innovators. Finally, optimizing grid operations can involve a myriad of ways (including pricing and rebates) that utilities, system operators, and regulators can encourage customers to modify their electrical loads in exchange for some form of compensation.[2]

New challenges to grid operation also include the integration of more distributed and variable energy

---

[1] For example, the US Environmental Protection Agency did not explicitly include grid optimization measures in its determination of the "best system of emission reduction" for the proposed Clean Power Plan regulations under section 111(d) of the Clean Air Act.

[2] Some of the technologies and policies used to optimize grid operations are relevant in the context of other GHG reduction strategies, or can be adopted as standalone strategies. In other words, there is intentional overlap between this chapter and other chapters in this document. In particular, readers will find overlapping references between this chapter and Chapter 10 (which focuses exclusively on losses in the transmission and distribution system), Chapter 23 (which focuses exclusively on demand response), and Chapter 26 (which discusses electricity storage, smart grid, electric vehicles, rate design, and other topics).

resources,[3] plus the inherently more diffuse nature of system operations associated with diverse customer ownership of distributed resources. Fortunately, intelligent grid capabilities, along with advanced communications and new grid technologies, are providing solutions to these new challenges.[4]

Many of the approaches considered in this chapter rely on or can be enhanced by some degree of "smart grid" technology. The "smart grid" – a suite of enabling technologies that are increasingly prevalent, but the potential of which has hardly been tapped in practice – is discussed in greater detail in Chapter 26. It is worth noting here, however, that the US Department of Energy[5] and many states[6,7] have launched smart grid or other grid modernization initiatives in pursuit of such opportunity. Several similar efforts are also underway in the private sector (e.g., by the Electric Power Research Institute [EPRI][8]).

Along with these new approaches, there are also several existing, mature technologies and technical solutions that can be applied in many areas of the electrical system. Many of these ways to improve operation of the grid fall into one of the following categories: conservation voltage regulation, volt-ampere reactive (VAR) control/power factor management, dynamic pricing and demand response (DR) programs, and well-placed storage to optimize the grid. These options are discussed in greater detail below.

a. Conservation Voltage Regulation (or Conservation Voltage Reduction)

Utilities typically maintain distribution grid voltages at the higher end of the 114- to 126-voltage range permitted by American National Standards Institute in order to provide a greater margin of safety in avoiding reliability issues (e.g., against changing loads on remote circuits). Conservation voltage regulation (CVR) can be exercised by both transmission system and distribution system operators, and is usually implemented by reducing voltages at the substation level to achieve power savings over short time periods.[9] Transmission and distribution systems are designed to operate within certain voltage tolerance limits. Utilities can save energy by operating the distribution system at the lower end of the acceptable voltage range. Reducing voltage also reduces the energy consumption of some consumer equipment without materially affecting service quality.[10] The grid system typically loses three to seven percent of the electricity that it carries while

---

[3] "Distributed energy resources" refers to small electricity generating sources (usually less than 1 megawatt capacity) typically installed at a customer's location. Such sources can be fossil-fueled (e.g., diesel generators installed for backup or emergency power), but increasingly they are renewable, such as photovoltaic (PV) solar systems installed on homes, businesses, and commercial locations or small-scale wind power installations. "Variable energy resources" generally refers to renewable generation sources. Passing clouds and nighttime reduce or eliminate PV solar output, and wind generation can vary over the day, from day to day, or during different weather patterns.

[4] "Intelligent grid" includes technologies popularly referred to as the "smart grid." These are an array of technologies enabling unprecedented utility control over the system and devices through the use of computers, sensors, two-way communications, micro-grids, and automation to seamlessly integrate and manage both the supply and demand for electricity. The concept of the intelligent grid also encompasses new aggregation services by a number of new third-party providers that deliver services to both system operators and utilities.

[5] More information on the US Department of Energy's grid modernization efforts is available at: http://energy.gov/oe/services/technology-development/smart-grid

[6] More information on the Massachusetts Department of Public Utility's grid modernization efforts is available at: http://www.mass.gov/eea/docs/dpu/electric/12-76-a-order.pdf

[7] More information on the New York State Department of Public Service's grid reform and modernization efforts is available at: http://www3.dps.ny.gov/W/PSCWeb.nsf/All/26BE8A93967E604785257CC40066B91A?OpenDocument

[8] EPRI. (2015, February). *The Integrated Grid: A Benefit-Cost Framework.* Available at: http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004878

[9] Utilities routinely operate at the high end of the 114- to 126-voltage range permitted by American National Standards Institute Standard C-84.1. Willoughby, R., & Warner, K. (2013, June 4).*Time to Take a Second Look at Conservation Voltage Regulation?* Intelligent Utility. Available at: http://www.intelligentutility.com/article/13/06/time-take-second-look-conservation-voltage-regulation

[10] Net benefits depend on the design of the distribution system, the types of loads on the system, and the generating resource mix. Motors and other constant power loads, for example, tend to draw more current to compensate for reduced service voltage levels. Voltage levels must be kept within American National Standards Institute specifications

continued on next page

delivering electricity to homes and businesses. But as discussed in Chapter 10, losses can rise to around 20 percent during periods of peak electricity demand, such as on hot summer days with elevated residential and commercial air conditioning load.[11] These losses have to be made up through additional generation. Additional generation, in turn, emits additional GHGs and criteria pollutants, contributing to the unhealthy air quality conditions that often coincide with system peak periods.

Utilities control line voltage by changing settings on equipment at the substation serving the line or on equipment connected to the line. Voltage drops gradually as electricity flows further from the substation, so utilities need to ensure that the voltage level at the "end of the line" is above the minimum standard. This can be challenging because changing factors such as weather, load, electric generating unit (EGU) operations, and design (and changes in design to meet changes in load with growth, for example) must be taken into account to ensure that the voltage levels are acceptable at all points at all times. Using advanced metering systems, utilities can now remotely monitor and control voltage levels more accurately on individual circuits, allowing voltage margins to be smaller without affecting service to customers. In doing so, utilities reduce energy consumption, peak loads, and reactive power needs, reducing upstream generation and its corresponding costs and emissions. Pilot projects matching such technologies and real-time operating systems show that energy savings and demand reductions of three percent are possible.[12]

b. Power Factor Management

The flow of electrical current through a wire induces a magnetic field. Called "induction," "reactive power," or just "VARs,"[13] this magnetizing effect is most pronounced in electric motors, transformers, lighting ballasts, and so on, and least pronounced in such applications as resistance heating. Unfortunately this effect consumes energy, thereby reducing the amount of energy actually left to perform useful work.

Power factor is a measure of this effect, the ratio of "real power" (the amount available for useful work) to "total power" or "apparent power" (the amount originally provided). Ideally this ratio would be 1:1, making power factor equal to 1.0. Unfortunately in the real world, highly inductive loads reduce power factor, often to 0.70 or less. At this level, 30 percent of the original power is consumed by inductive loads and is unavailable to do useful work. Depending on requirements, it may be possible to adjust the output of existing online generators to increase the reactive power, or VAR output, to help meet grid requirements.[14] Otherwise costly steps, like bringing on additional generation and ensuring adequate transmission capacity, then have to be taken by grid operators in order to meet demand.[15] It is not surprising, then, that utilities

---

to avoid the possibility of heating or damage to motors when operated at reduced voltage levels. Some loads may use the same amount of power over time, even if they consume less when voltage is lowered. In such cases, the redistribution of power consumption over a longer period may still reduce peak demand and the operation of less efficient generating units. See: Pratt, R., Kintner-Meyer, M. C. W., Balducci, P. J., Sanquist, T. F., Gerkensmeyer, C., Schneider, K. P., Katipamula, S., & Secrest, T. J. (2010, January). *The Smart Grid: An Estimation of the Energy and CO_2 Benefits.* Pacific Northwest National Laboratory. Publication no. PNNL-19112. Prepared for the US Department of Energy. Available at: http://energyenvironment.pnl.gov/news/pdf/PNNL-19112_Revision_1_Final.pdf

[11] Lazar, J., & Baldwin, X. (2011, August). *Valuing the Contribution of Energy Efficiency to Avoided Marginal Line Losses and Reserve Requirements.* Montpelier, VT: The Regulatory Assistance Project. Available at: www.raponline.org/document/download/id/4537. Also, see: EPRI. (2008, March). *Green Circuit Field Demonstrations.*

[12] Supra footnote 9.

[13] Reactive power is often referred to simply as VAR or "VARs" for "volt-ampere reactive," its unit of measure.

[14] For example, combustion turbines can be used as synchronous condensers for reactive control. This operation includes the start and stop of the combustion turbine in order to bring the generator to synchronous speed. The combustion turbine is then de-clutched from the generator and the generator operates as a "motor" providing reactive services to the grid. Areas that have markets for reactive power provide payment for operation in this manner.

[15] In areas where there is a market for reactive power, such as PJM, generator owners/operators may receive compensation for their reactive output. Otherwise, generator owners/operators may be hesitant because megawatt output (and hence electrical sales) may have to be reduced (depending on the total load of the generator) to ensure that the generator is not loaded beyond acceptable limits. Also, some small generating units may be (or may have been) modified to act as synchronous condensers to help control system reactive power (primarily in areas where there is a viable reactive market).

often charge extra costs to commercial customers who have a power factor below some limit (e.g., 0.90 to 0.95).

Power factor management or "VAR control" refers to practices that maintain voltage levels at all points of the distribution systems for all load conditions.[16] Power factor can be "corrected" through technologies like capacitors or inductors that act to cancel the inductive or capacitive effects of the load, respectively. Automatic power factor correction units monitor power and switch blocks of capacitors in or out of service as required.[17] Additional benefits of power factor management include lower losses, better voltage regulation, and additional available system capacity.

Power factor correction is increasingly being built into consumer electronics as well. Energy Star's® Program Requirements for Computers Version 5.0, for example, calls for a power factor of ≥0.9 for computers. Energy Star® does not impose a minimum power factor on new residential refrigerators,[18] however, and even some highly rated models have relatively poor power factors.[19]

In summary, power factor management can both improve the working energy available from the system and reduce line losses made more severe by high current levels resulting from poor power factors. A more thorough discussion of this topic can be found in Chapter 10.

c. Demand Response

Demand response reflects a variety of approaches – typically financial in nature, such as rate designs, price signals, or rebates – that can motivate electricity end-users to curtail their load or shift it from peak to off-peak periods. DR is typically considered a tactic to address shortfalls in generation when peak electricity demand approaches or exceeds available supply. However, it is equally effective in addressing peak constraints imposed by the transmission and distribution grid as well. Shifting or curtailing loads reduces stress on the grid, lessens line losses, and can avoid or delay the need for upgrades to the grid system. In doing so, DR implicitly reduces reliability risks associated with stressed grid systems.

Increasingly sophisticated DR services can also extend to the delivery of ancillary services to grid operators. Since November of 2011, for instance, ENBALA Power Networks has aggregated loads to provide balancing services in PJM.[20] Aggregators of DR services are capable of facilitating the delivery of a wide range of services at both the distribution and bulk transmission level.

In addition to other benefits, DR may also provide a cost-effective way to maintain or improve grid system performance in the face of increasing levels of variable energy resources and distributed generation (e.g., renewables). As such, DR and the tools by which it is implemented (like time-of-use pricing and advanced dynamic pricing) will gain in importance with increasing penetration of distributed generation and electrification of the passenger vehicle fleet.[21]

Curtailment or shifting of loads from peak to off-peak periods can provide significant energy savings because losses increase with the square of demand, causing losses at critical peak period to be much larger than average losses. It is important to recognize, however, that DR may not always be beneficial in reducing GHG emissions. When grid users curtail their load under a DR program but shift to higher-emitting backup or standby generation, GHG

---

[16] Uluski, B. (2011). *Volt/VAR Control and Optimization Concepts and Issues.* EPRI. Available at: http://cialab.ee.washington.edu/nwess/2012/talks/uluski.pdf

[17] Power factor correction technologies are advancing rapidly. Distribution system capacitor banks can now be operated using real-time voltage data from advanced metering infrastructure to optimize voltage and VAR control. Power factor correction of high-voltage power systems may require specialized devices to automatically provide shunt capacitance or shunt reactance as required to maintain acceptable transmission line voltage. These systems compensate for sudden changes of power factor much more rapidly than contactor-switched capacitor banks or shunt reactors, and require less maintenance.

[18] See: http://www.energystar.gov/ia/products/appliances/refrig/NAECA_calculation.xls?f1ac-7464

[19] Regulatory Assistance Project Senior Advisor Jim Lazar measured power factor on two Energy Star® refrigerators in 2013 at 0.39 and 0.41. This suggests that the Energy Star® criteria, which address only kilowatt-hour usage per cubic foot, need to be revised.

[20] Hurley, D., Peterson, P., & Whited, M. (2013, May). *Demand Response as a Power System Resource: Program Designs, Performance, and Lessons Learned in the United States.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/6597

[21] For a discussion of time-varying pricing, see: Faruqui, A., Hledik, R., & Palmer, J. (2012, July). *Time-Varying and Dynamic Rate Design.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://raponline.org/document/download/id/5131

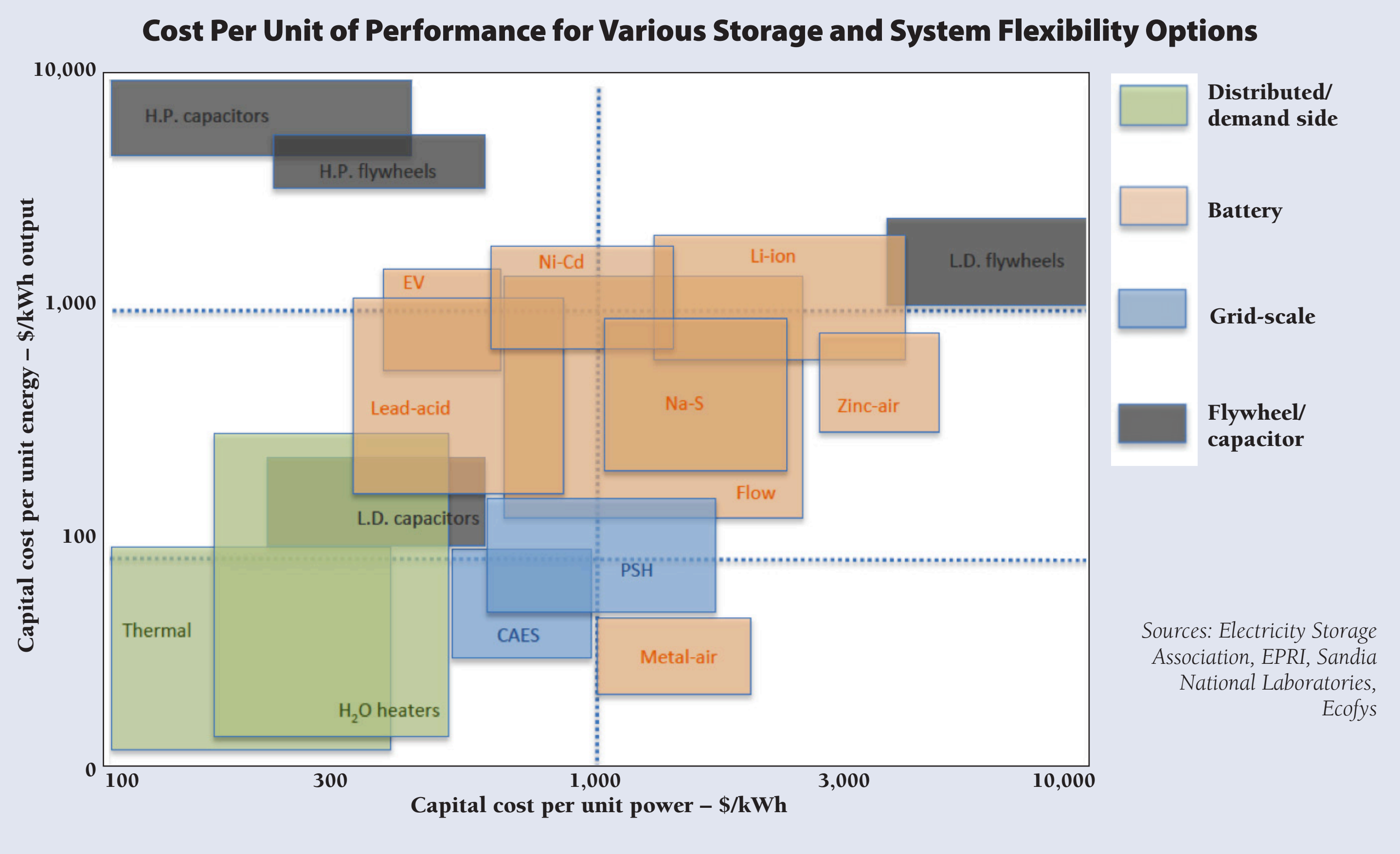
emissions could actually increase. Chapter 23 provides a comprehensive discussion of DR as a GHG emissions reduction strategy.

d. Storage of Electrical and Thermal Energy

Storage of electrical energy can be expensive, but it can also be an important part of a comprehensive approach to system optimization. Although there are multiple technologies currently available, including batteries, pumped hydro storage, compressed air energy storage, flywheel technology, and others, all are expensive. This is partly attributable to the nascent state of most electricity storage options, and partly to the inherent losses incurred as electricity is converted into another form of energy (e.g., mechanical or chemical) for storage and then re-converted later back to electricity. By contrast, thermal energy can be stored in the form it is eventually used (e.g., solar thermal hot water, ice, or chilled water), so it does not suffer conversion losses. Both electrical and thermal energy storage can provide targeted options to help optimize the grid.

Storage can serve multiple roles. One is bulk energy storage; pumped hydro has been used extensively for this purpose.[22] During the storage phase, when water is pumped up to an elevated impoundment, slightly more energy is used than is generated in the production phase, when stored water is released to drive turbines. Pumping usually occurs during low load levels (e.g., at night); subsequent water releases enable generators to better respond to peak demands. The economics work because peak power is much more valuable, and using pumped storage can avoid incremental fossil generation at peak times. Pumped hydro generators typically lie in remote locations and require additional transmission investment to provide pumping power and to bring their capacity to load centers. Another role for storage is to provide fast response to assist with ramping and system reliability; here batteries and flywheel systems seem to be the preferred technologies. Compressed air storage could also be an option. There are two working, utility-scale compressed air storage systems in the world, one in the United States and the other in Germany. Other large-scale technolo-

Figure 5-1


Cost Per Unit of Performance for Various Storage and System Flexibility Options

Sources: Electricity Storage Association, EPRI, Sandia National Laboratories, Ecofys

---

[22] For more information on pumped hydro, see: *Pumped Hydro.* The National Hydropower Association. Available at: http://www.hydro.org/tech-and-policy/technology/pumped-storage/

gies are emerging as well. Figure 5-1 shows the relative cost characteristics of different types of storage that can provide additional flexibility for grid operations.

There are already situations in which electricity storage can be cost-effective and should be pursued. These include placement at strategic points where storage can provide supplemental capacity to meet peak loads, or a place to "park" surplus generation created by high renewable or nuclear generation at times when it isn't needed for current demand (e.g., because of high winds occurring at night). Strategically placed storage like battery banks can also help smooth wind generator output to enable more gradual ramping of other generation sources, including fossil-fueled electricity generating units, reduce localized peak loads (and associated losses) and thereby postpone or avoid more expensive transmission and distribution system upgrades, and even provide ancillary services to the grid, such as frequency control and voltage support.

Advances in two-way communications between the grid and devices – an element of what is commonly called the "smart grid" and increasingly referred to as part of "the internet of things" – may offer special promise regarding electricity storage. This prospective opportunity concerns use of new and existing batteries, such as those in electric vehicles (EVs) and uninterruptible power supplies, selectively charging them when power is available (e.g., during low night loads) and drawing upon these collective resources to help supply the grid during peak load periods.

An early application of this approach is likely to be grid control of EV chargers,[23] turning them from "charge" to "draw" as power supply market conditions warrant or to meet ancillary service needs on the grid. Sophisticated selective discharge systems – called "vehicle to grid" (V2G) systems – are being tested today and may emerge as a valuable grid resource within this decade. Even before such "bidirectional" charging infrastructure becomes widely available, however, plug-in EVs can deliver value to the grid in the form of ancillary services. Furthermore, EVs may be able to assist in the integration of renewable energy resources into the grid, by providing storage for renewable energy output when renewables might otherwise be curtailed.[24,25] The economics of such approaches must be compared to the full value of the benefits they provide (i.e., generation, transmission, distribution, capacity, environmental, and other), not just the distribution capacity upgrades they may help defer.[26]

There are several different types of thermal energy storage technologies as well; many are well proven historically, and several reflect new technological advancements. Residential hot water heating is a good example of the former. Home hot water heating is concentrated in the morning and evening hours, when residential consumers get up in the morning and again when they return home at the end of the day. By shifting water heating load from morning and evening to mid-day (when PV is most active) and overnight (when load is lowest), and "storing" the heated water until used, water heating's electricity requirements can help level overall demand on the grid rather than contributing to its peaks. A related strategy "supercharges" water heaters to higher temperatures, and uses a blending valve to deliver normal hot water temperatures to residents. In this manner, the grid operator can use "storage capacity" within existing water heaters to reduce electricity demand during peak periods.[27]

Air conditioning, both residential and commercial, represents a dominant summer electrical load in most of the United States, contributing greatly to afternoon and early evening peaks. Requiring new central air conditioners and large-building cooling systems to have two hours of thermal storage in the form of ice or chilled water would allow air conditioning loads to be time-shifted, much like the supercharging of hot water heaters noted previously. These types of devices are commercially available today, and they actually provide both capacity (peak) and energy savings, because they make ice or chilled water at night, when temperatures are lower and chilling units operate more efficiently.[28]

---

[23] Permission for grid control would likely be at the vehicle owner's option, and in return for financial consideration.

[24] Keay-Bright, S., & Allen, R. (2013, June 24). *Policy Brief: EU Power Policies for PEVs: Accelerating from here to en masse.* Montpelier, VT: The Regulatory Assistance Project. Available at: www.raponline.org/document/download/id/6620

[25] M. J. Bradley & Associates for The Regulatory Assistance Project and International Council on Clean Transportation. (2013, July). *Electric Vehicle Grid Integration in the US, Europe, and China: Challenges and Choices for Electricity and Transportation Policy.* Available at: www.raponline.org/document/download/id/6645

[26] Lazar, J. (2014, January). *Teaching the "Duck" to Fly.* Montpelier, VT: The Regulatory Assistance Project. p. 16. http://www.raponline.org/document/download/id/6977

[27] Supra footnote 26 at p. 10.

[28] Ibid at p. 12.

Finally, solar thermal generation can time-shift generation itself by using solar energy to heat a fluid that is then stored to generate electricity during later hours. Operating at a slightly higher cost than PV generation, this form of storage technology has been deployed in Arizona with fully six hours of successful storage.[29,30]

e. Other Opportunities for Optimization

There are other avenues for improving the performance of the grid, including numerous hardware improvements to reduce system losses that are the focus of Chapter 10. Other opportunities to achieve small but significant improvements are also possible based on the physical character of the grid system.

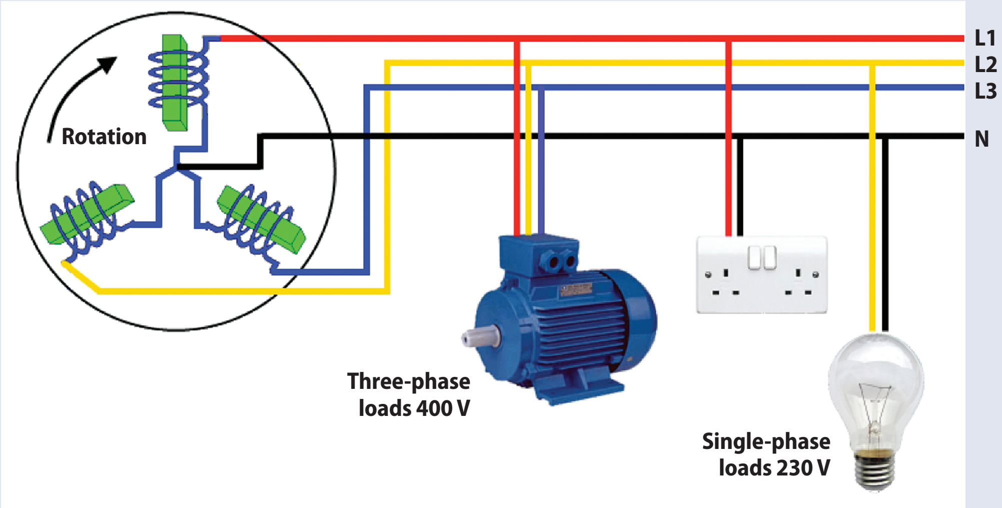
Most bulk transmission and distribution systems are based on three-phase alternating current power systems. Each phase is represented by a generator coil passing through a magnetic field on the motor. The three phases of the system can be delivered at a high voltage to large three-phase loads, or can be delivered as individual phases at lower voltages, as is commonly found in homes. Figure 5-2 illustrates this relationship.

High-voltage transmission systems are typically balanced, but electricity delivered on single-phase circuits is more susceptible to imbalances owing to variations in the loads served. As a result, distribution systems are often highly unbalanced, increasing system losses. Furthermore, the energy consumption of electrical loads changes continuously, which makes the balancing process challenging. Balancing three-phase loads periodically throughout a network can reduce losses significantly. Balancing can be done relatively easily and offers considerable scope for cost effective reduction in system losses. Use of smart grid assets to monitor individual phases, and to shift single-phase loads from one phase to another can also help correct and reduce unwarranted losses.

Joints and connections between two conductors or other components in the construction of the physical transmission system can also be a source of electricity losses attributable to aging and corrosion. Minimizing the number of joints, ensuring proper joining techniques, and conducting regular inspection and maintenance through thermal imaging and other techniques can help reduce losses from loose or corroded connections.[32,33]

Figure 5-2

Three-Phase and Single-Phase Electricity Distribution[31]



---

[29] Supra footnote 26 at p. 9.

[30] Owano, N. (2013, October 11). *Arizona solar plant achieves six hours after sun goes down.* Phys.org. Available at: http://phys.org/news/2013-10-arizona-solar-hours-sun.html

[31] McFadyen, S. (2012, April 17. *Three Phase Power Simplified.* Available at: http://myelectrical.com/notes/entryid/172/three-phase-power-simplified.

[32] Electrical Engineering Portal. (2013, August). *Total Losses in Power Distribution and Transmission Lines.* Available at: http://electrical-engineering-portal.com/total-losses-in-power-distribution-and-transmission-lines-1

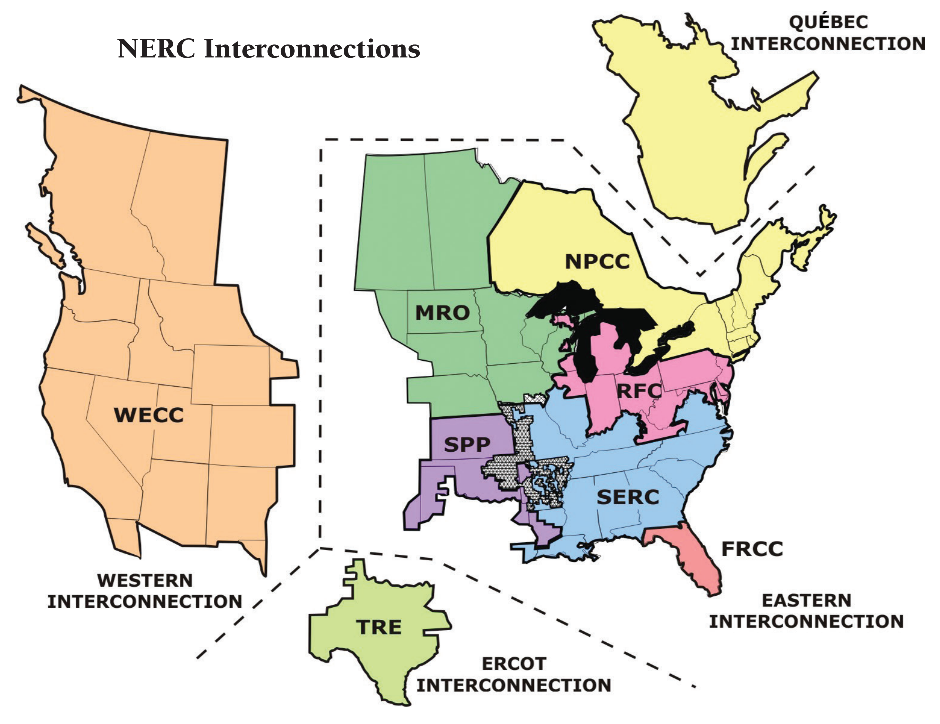
[33] Supra footnote 31 and, Black, J. W., Tinnium, K. N., Larson, R. R., Wang, X., & Johal, H. (2012, March 29). Patent Application Title: *System and Method for Phase Balancing in a Power Distribution System.* Available at: http://www.faqs.org/patents/app/20120074779

2. Regulatory Backdrop

The technologies discussed in this chapter are either regulated by federal requirements, state regulations, or voluntary utility industry standards. In general, the federal government generally has jurisdiction over bulk transmission lines via the Federal Energy Regulatory Commission (FERC). State public service commissions have jurisdiction over distribution lines, usually defined as the power lines that feed into homes or businesses. There are many inconsistencies in this paradigm, however, a number of which reflect the evolving nature of the electric grid.

Figure 5-3

Major North American Electricity Interconnections[35]



Power is distributed across the United States over high-voltage transmission networks linked by three major interconnections: the Eastern Interconnection, the Western Interconnection, and the Electric Reliability Council of Texas (ERCOT).[34] The North American Electric Reliability Corporation (NERC) oversees these three broad interconnections for reliability purposes. The three major interconnections are further subdivided into eight reliability planning areas, also under the oversight of NERC. NERC has adopted specific reliability standards that are legal requirements under FERC's authority. These regions are shown in Figure 5-3.

Because 47 states (excluding ERCOT, Hawaii, and Alaska) have transmission systems that are interconnected with other states' transmission networks, FERC regulates most bulk transmission, setting its rates and standards of service.[36]

Within the NERC regions, the minute-to-minute coordination of electricity supply with demand is managed by RTOs, ISOs, or individual utilities for their specific control areas. Both RTOs and ISOs are voluntary organizations established to meet FERC reliability and other requirements. As such, they plan, construct, operate, dispatch, and provide open access to transmission services.[37]

---

[34] When completed, the Tres Amigas project will significantly enhance the linkage between these three existing interconnection "islands," improving reliability in all three interconnection areas and providing a pathway for the transfer of substantial generation from renewable resources between the interconnections. Additional information is available at: http://www.tresamigasllc.com/

[35] See NERC website: http://www.nerc.com/AboutNERC/keyplayers/Documents/NERC_Interconnections_Color_072512.jpg

[36] Not all transmission is subject to FERC jurisdiction. Public power entities such as the New York Power Authority, Arizona's Salt River Project, North Carolina's Santee Cooper, or the Los Angeles Department of Water and Power are not under FERC jurisdiction. Federal agencies also self-govern, so the Bonneville Power Administration, the Western Area Power Administration, and the Tennessee Valley Authority all fall outside of FERC's authority. Finally, most of Texas and all of Hawaii and Alaska are outside FERC jurisdiction because they are not connected, or not tightly connected, to the interstate transmission grid. See: Brown, M., & Sedano, R. (2004). *Electricity Transmission: A Primer.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/812

[37] Lazar, J. (2011). *Electricity Regulation in the US: A Guide.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/645

Most grid optimization technologies must comply with federal, state, market, or utility rules, or some combination thereof. For instance, the rules that enable customer-side resources (such as DR) to participate in the delivery of grid services are defined in ISO/RTO market rules and by the utilities that operate the electricity distribution grid in areas outside of (or in addition to) formal wholesale markets regulated by FERC. FERC also regulates DR in the context of bulk transmission and wholesale markets. State regulators may also require certain levels of DR as a matter of state policy.

Regulatory oversight for conservation voltage reduction is split between federal and state regulators. Regulatory oversight at the level of the distribution and sub-transmission level comes from state regulatory commissions, whereas oversight at the transmission level comes from FERC and NERC.

To date, most options like power factor management, storage, and DR have been subject to market forces with little direct oversight by regulators. However, utilities typically have an obligation, enforced by utility regulators, to pursue low operations and maintenance costs on behalf of ratepayers as part of requirements for "just and reasonable" rates. So indirectly, utilities must consider these options if they can help reduce costs. California also took an initial step toward regulating electricity storage in late 2013, when the California Public Utilities Commission adopted requirements for its three largest utilities to procure 1325 megawatt-hours (MWh) of storage by 2020.[38]

3. State and Local Implementation Experiences

Most of the capabilities discussed in this chapter – including conservation voltage reduction, power factor optimization, phase balancing, and certain storage and DR capabilities – have existed in the past, but are being materially enhanced by the grid's evolution to two-way communications and automation (i.e., the "smart grid"). The enhanced versions of these approaches are relatively recent or just now emerging, so implementation experiences are limited. Accordingly, the discussion below focuses on pilot initiatives and reasons to expect greater benefit from these approaches in the future.

a. Conservation Voltage Reduction, Phase Balancing, and Power Factor Management

Utilities and system operators have used voltage reduction during capacity shortages for many years. In fact, ISO New England's operating procedures include it among the actions that the system operator may take to avoid involuntary load curtailments (i.e., "brownouts" or "blackouts"). The ISO estimates that a five-percent voltage reduction saves about 421 megawatts (MW) in its 28,000-MW system, approximately 1.5 percent of required capacity.[39] Emissions saved or avoided by this technique are discussed below.

The Northwest Energy Efficiency Alliance sponsored an extensive load research and field study of CVR with 11 utilities in the Pacific Northwest involving 31 transmission lines and ten substations from 2004 to 2007.[40] According to the project report, "operating a utility distribution system in the lower half of the acceptable voltage range (i.e., 114–120 volts) saves energy, reduces demand, and reduces reactive power requirements without negatively impacting the customer." The study estimated CVR could save one to three percent of total energy, two to four percent of kilowatt (kW) demand, and four to ten percent of kVAR demand.[41]

Little is known about how CVR may interact with smart grid technologies. As part of its Smart Grid City project in Boulder, Colorado, Xcel Energy is testing dynamic voltage/VAR optimization based on monitored real-time conditions. A recent review by Pacific Northwest National Laboratory

---

[38] California Public Utilities Commission. (2013, October 21). Decision 12-10-040, Adopting Energy Storage Procurement Framework and Design Program. Available at: http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm

[39] See: ISO-NE. *OP-4 - Action During a Capacity Deficiency.* Appendix A. Available at: http://www.iso-ne.com/rules_proceds/operating/isone/op4/op4a_rto_final.pdf

[40] Global Energy Partners, LLC for Northwest Energy Efficiency Alliance. (2008, June 27). *Utility Distribution System Efficiency (DEI): Phase 1. Final Market Progress Evaluation Report.* Available at: http://neea.org/docs/reports/utility-distribution-system-efficiency-initiative-dei-phase-1-final-report-no-3.pdf

[41] Ibid at p. E-1. kVAR Volt-Ampere Reactive defined: In alternating current power transmission and distribution, volt-ampere reactive (var) is a unit used to measure reactive power in an AC electric power system. Reactive power exists in an ac circuit when the current and voltage are not changing at the same time.

concluded that, although additional research is needed, combining VAR control with smart grid technologies could potentially reduce total electricity consumption by two percent incrementally beyond the savings provided by CVR as practiced today.[42]

The EPRI launched a "Green Circuits" project in 2008 to build on the Northwest Distribution Efficiency Initiative by expanding field deployments of technologies and strategies and testing smart grid measurement, communication, and control.[43] Its goals were to improve modeling and loss analysis methods, analyze the economics of various strategies to improve distribution efficiency, and develop general guidelines for improving efficiency as a function of circuit and customer load characteristics.

The project involves 24 utilities and related organizations in 33 states and four countries. Roughly 90 circuits in rural and urban areas are included. Initial studies have been completed for 50 circuits. Distribution efficiency options were modeled as modifications to the base case, including:

- *Voltage optimization/CVR* – keeping transmission feeder line voltage in the lower band of the allowed range;[44]
- *Phase balancing* – rearranging loads on each phase of the circuit to lower the current on the most heavily loaded phase(s); and
- *Power factor correction/reactive power optimization* – adding capacitor banks or modifying switching schemes.

Hardware solutions modeled include:

- *Re-conductoring* – replacing selected conductors (wires) in the transmission and distribution systems; and
- *High-efficiency transformers* – replacing lower-efficiency line transformers with higher-efficiency units.

The average CVR savings factor – the change in load resulting from a one-percent reduction in voltage – was 0.79 percent, with a range of 0.66 to 0.92 percent. That's higher than determined in the Northwest Energy Efficiency Alliance study described previously, likely owing to the higher levels of resistive electric space and water heating loads where the Alliance conducted its study. The next phase of the EPRI project will validate these preliminary findings, assess costs and benefits, test the reaction of specific customer end-use devices to voltage optimization using advanced metering infrastructure data, and evaluate additional efficiency measures, such as coordination with distributed resources for loss reduction and load management through distribution automation.[45]

To optimize system voltage requires data on real-time voltage levels, which can be provided by smart meters and associated smart grid telecommunications equipment, along with voltage regulators at substations and on longer distribution feeder lines from the transmission system.

Utilities now have access to advanced modeling tools for the power system from the extra high voltage transmission system right down to the customer meter. Advanced metering infrastructure and GIS data now make it possible to optimize every line and distribution feeder for voltage control options, using equipment such as capacitors and static VAR compensators. The effects of CVR can be verified and even predicted.

b. Demand Response

Demand Response is now widely used to deliver a variety of grid services, as Chapter 23 discusses in detail. All organized markets in the United States now use or plan to use DR for ancillary services, and hundreds of local distribution utilities operate some form of DR program. DR is also used in energy markets and to deliver capacity-related services. Third-party aggregators (e.g., EnerNOC) play an important part in the delivery of DR in organized markets.

Price-based DR has long been available at the level of the

---

[42] Based on research sponsored by the Northwest Energy Efficiency Alliance and engineering estimates for dynamic optimization of voltage and reactive power. Assumes 100-percent penetration of the required smart grid technologies in 2030. Pratt, R., Kintner-Meyer, M. C. W., Balducci, P. J., Sanquist, T. F., Gerkensmeyer, C., Schneider, K. P., Katipamula, S., & Secrest, T. J. (2010, January). *The Smart Grid: An Estimation of the Energy and CO_2 Benefits.* Publication no. PNNL-19112. Pacific Northwest National Laboratory for the US Department of Energy. Available at: http://energyenvironment.pnl.gov/news/pdf/PNNL-19112_Revision_1_Final.pdf

[43] Material in this section is based on information from Karen Forsten, EPRI, March 2010.

[44] Voltage set point = 118.5 Volts (V); bandwidth = 2 V (+/– 1 V).

[45] Coordination with distributed resources for loss reduction refers to the dispatching of distributed generation to supply power to a transmission feeder line, and thus reduce line losses during peak loads. Load management through distribution automation means controlling customer loads by remote means to limit peak load.

vertically integrated distribution utility in the form of time-of-use pricing or some form of interruptible rates. Almost all utilities in the United States offer some form of time-of-use and interruptible tariffed rates and have for decades. Advanced metering infrastructure is enabling much more dynamic pricing arrangements in the form of critical peak pricing, real-time pricing, and peak-time rebates. There is available a growing body of experience with these frameworks in the various pilot program initiatives.

c. Energy Storage

As noted earlier, the storage of electricity can be relatively expensive. But if one expands the idea of storage to include thermal storage capabilities on the customer side of the meter (e.g., storing hot water in water heaters rather than electricity in batteries), the potential is quite large. Recall that electricity demand met through either the storage of electricity or its end products (e.g., heated water) can be a resource equivalent to acquiring additional generation. Against this measure, some forms of storage (see Figure 5-1) are already more cost-effective than new fossil plants, plus they provide the grid operator with more operating flexibility and avoid new criteria pollutant and GHG emissions that would also accompany additional fossil-fueled generation. Furthermore, electricity storage capabilities promise to improve significantly over time with the electrification of vehicles and other technological developments. And as noted earlier, California has recently established electricity storage procurement requirements for its major utilities.

Although there are many storage technologies available, some of the least expensive are those involving distributed thermal heat. The United States has about 45 million electric water heaters in service, and residential hot water use is concentrated in the morning and evening hours, when residential consumers are getting up in the morning and again when they return home at the end of the day. Residential water heaters are thus excellent targets for load control, and more than 100 rural electric cooperatives already operate simple load control programs using members' electric water heaters. By shifting water heating load from morning and evening to mid-day (when solar PV is greatest) and overnight (when wind and thermal capacity may be underutilized), water heating energy requirements can be served far more economically than at peak periods. One favored strategy involves "supercharging" water heaters to higher temperatures during off-peak electrical demand periods (coupled with a blending valve to deliver normal hot water temperatures to homeowners). In this manner, the grid operator can use the ability to store electricity as hot water within existing water heaters.

Using these water heaters to help balance the loads and resources of an urban utility may require new institutional arrangements (e.g., voluntary agreements, contracts, compensation, and so forth), but the necessary technologies are readily available and can be installed quickly and managed easily. To date, most water heater load control programs have used radio signaling systems, but with the communication systems that have been installed by many electric utilities to support advanced metering infrastructure, it will also be possible to control electric water heaters remotely from utility control centers.

Electric water heating is dominant in the Pacific Northwest and in the south, whereas natural gas water heating is dominant in California. But even the investor-owned electric utilities in California have approximately ten-percent electric water heat saturation – about one million installed units – primarily in mobile homes and multifamily housing. One million electric water heaters could enable up to 4000 MW of capacity and up to 10,000 MWh per day to be shifted as needed. Projects are being advanced in Canada and Hawaii to use electric water heating controls to add system flexibility.[46]

Thermal storage systems can shift cooling requirements just as effectively as they can shift heating requirements. Systems that make ice during off-peak hours and then use that ice for cooling during on-peak periods – instead of relying on an electric air conditioning compressor – are already commercially available. They provide an excellent alternative for storing off-peak energy, such as nighttime generation from wind turbines. Using direct control of these cooling systems and other air conditioning systems with cold storage could greatly increase DR capabilities. The use of ground source heat pumps for residential heating and cooling systems could be similarly useful in various locations and under certain conditions.

As noted earlier, electricity can be directly stored in compressed air storage systems, mechanical flywheel systems, some chemical phase-change systems, utility-scale battery banks, and even existing batteries, such as those in EVs and uninterruptible power supplies. These systems can be used to supply power to the grid, but they can also be managed to help meet ancillary service needs on the

---

[46] Supra footnote 26.

grid (e.g., by turning them off and on, drawing on them as power "sources," or charging them as power "sinks") as power supply market conditions change.

The electrification of the transportation system would use off-peak electricity (i.e., nights and weekends) from the grid to charge the vehicles. This would enhance the efficiency of the grid by shifting electricity use to off-peak nighttime hours, reducing the difference between off-peak and peak demand levels and allowing EGUs to operate more steadily and efficiently. EVs also are capable of providing electric services to the grid – a concept called "vehicle-to-grid" (V2G). A large number of EVs, plugged in and aggregated together as a single resource, could serve as a large "battery on the grid." One service that these vehicles can provide is regulation, used to balance variations in load by correcting for short-term changes in electricity use that might affect the stability of the power system. Regulation helps match generation and load and adjusts generation output to maintain the desired frequency.[47]

In an initiative with the University of Delaware and NRG Energy, a group of EVs is providing regulation services through the PJM Regulation Market. This project aggregates power from multiple EVs to create one larger power resource, rather than individual, smaller ones, and it has demonstrated for the first time that V2G technology can sell electricity from EVs to the power grid. Like large-scale batteries, this kind of energy storage can also store wind power generated at night for use during the day when demand is higher.[48]

A study on EVs in Texas found that if vehicle charging is optimized, an EV fleet of up to 15 percent of light duty vehicles could actually decrease electric generator nitrogen oxide emissions, even while increasing load. This is because selectively increasing system load allows generating units to run more efficiently, and allows system operators to deploy more efficient units. The same study found that using the batteries in the vehicles to provide V2G services could also reduce the sulfur dioxide and carbon dioxide (CO_2) emissions impacts of increased load from EVs. V2G services include using batteries for spinning reserves, frequency regulation, and energy storage to address peak load.[49] The study did not compare EVs to conventional vehicles, however.[50,51]

One recent study suggested that the value EVs could bring to the grid would compensate for a significant proportion of their annual electricity "refueling" cost. The study modeled three unidirectional grid-to-vehicle services: one-way frequency response/primary reserve (i.e., for short durations), one-way secondary reserve (i.e., for longer durations), and energy storage to reduce curtailment of renewable energy output. The total value of the three services was estimated to be $192 per year in 2020, split fairly evenly between the three services. This value is predicted to decline over time to $120 per year by 2050, as the value of frequency response per participant reduces significantly with market saturation. By contrast, the value of reduced renewable energy curtailment and reserves stays fairly constant to 2050 such that EV refueling costs in 2050 may be offset by 50 percent.[52]

Beyond issues associated with EVs' potential impact on grid optimization lies a broader set of questions related to the US Environmental Protection Agency's proposed Clean Power Plan (CPP). States choosing a mass-based pathway for complying with the CPP, for instance, could be discouraged from pursuing large-scale EV penetration because emissions from EGUs (which are covered by the CPP) could increase owing to additional charging load, even though overall GHGs from motor vehicles (which the CPP does not cover) could decline.[53]

---

[47] PJM Fact Sheet. (2014, February 2). *Electric Vehicles and the Grid.* Available at: http://www.pjm.com/~/media/about-pjm/newsroom/fact-sheets/electric-vehicles-and-the-grid-fact-sheet.ashx

[48] Supra footnote 47.

[49] "Spinning reserves" are generation resources that are kept on standby and are able to provide capacity to the grid when called by the system operator. "Frequency regulation" is a service, typically provided by a power plant, which system operators use to maintain a target frequency on a power grid. Signaled, a frequency-regulating unit will either increase or decrease its output or load to re-balance system frequency.

[50] Supra footnote 25.

[51] Sioshansi, R., & Denholm, P. (2009). Emissions Impacts and Benefits of Plug-In Hybrid Electric Vehicles and Vehicle-to-Grid Services. *Environ. Sci. Technol.*, *43*(4):1199–1204. Available at: http://pubs.acs.org/doi/abs/10.1021/es802324j

[52] European Climate Foundation. (2013). *Fuelling Europe's Future: How Auto Innovation Leads to EU Jobs.* Available at: http://www.camecon.com/EnergyEnvironment/EnergyEnvironmentEurope/FuellingEuropesFuture.aspx

[53] Toor, W., & Nutting, M. (2014, November 30). *Southwest Energy Efficiency Project (SWEEP) and the Electric Vehicle Industry Coalition (EVIC), Comments on the Treatment of Electricity Used by Electric Vehicles in the EPA's Proposed Clean Power Plan Rule.* Docket ID No. EPA-HQ-OAR-2013-0602. Available at: http://www.seealliance.org/wp-content/uploads/SWEEP-EVs.pdf

4. GHG Emissions Reductions

As currently applied during periods of capacity shortfalls at the level of bulk transmission, the potential GHG reductions from CVR are limited. If the practice becomes more widespread at the transmission and especially the distribution levels, the impacts could increase significantly. As noted earlier, distribution system savings from a one-percent reduction in voltage corresponds to a 0.4- to 0.8-percent reduction in total generation requirements. Taking the midpoint, a 0.6-percent reduction in generation requirements nationally, at system-average emissions rates for fossil generators, would be approximately 22.8 million MWh, or the equivalent of 16 million metric tons of CO_2 emissions reduction.

The Northwest Energy Efficiency Alliance study estimated that CVR could save one to three percent of total energy, two to four percent of kW demand, and four to ten percent of kVAR demand. Every kWh saved is equivalent to an annual reduction in CO_2 emissions of 0.0007 metric tons. To put this in perspective, a small- to medium-sized utility serving 1 billion kilowatt-hour in load annually could reduce CO_2 emissions by 6896 metric tons for each one-percent reduction in energy losses, the equivalent in terms of CO_2 emissions of taking 1452 passenger cars off the road.[54] The report points out that major distribution efficiency improvements beyond CVR can achieve even higher levels of energy savings and emissions reductions.

Demand response and well-placed distributed storage can reduce losses in the transmission and distribution of electricity by reducing loads during periods at which power lines and other equipment are most stressed and losses can be as high as 20 percent. Recall that losses increase by the square of the current traveling through the system, so reducing current during peak periods can yield substantial benefits. By reducing losses during peak periods, these technologies also help avoid periods in which some of the least efficient fossil generation is called up to operate in order to meet peak electricity demands. The geographic impacts of the resulting emissions reductions, however, are likely to be highly variable. Also, to ensure that the environmental benefits of DR are realized, air regulators will need to ensure that inefficient backup diesel generation is used only sparingly (i.e., in emergencies) rather than regularly by those curtailing grid electricity use under DR programs. Chapter 23 provides a more comprehensive discussion of the GHG reduction potential of DR.

The impacts of power factor management or VAR control and phase balancing will be comparable to those that are associated with emissions reductions from energy efficiency program initiatives, because the practical effect of VAR control is to improve the ability of the system to deliver real power available to do work.

Among many implementation questions associated with the US Environmental Protection Agency's proposed CPP are the issues of how grid-related GHG reductions would be allocated to or claimed by the states covered by a grid control area, and how such reductions would be accounted for in state compliance plans. Given the interstate nature of the electricity grid, it may be challenging to attribute GHG savings from these measures to individual states.

5. Co-Benefits

Strategies to optimize the grid will produce co-benefits within the utility system and for utility customers by reducing both the capacity and the energy requirements of the system. In addition, by reducing the amount of electricity generated to meet demand, emissions of criteria and hazardous air pollutants will be reduced in rough proportion to the reductions in GHG emissions. The full range of co-benefits that can be realized through grid optimization is summarized in Table 5-1.

The array of existing and anticipated "smart grid" technologies described in this chapter can reasonably be expected to enable a variety of control actions that in the aggregate can provide or contribute to the co-benefits listed in Table 5-1, including improved grid reliability. It is important to note, however, that "smart" technologies can introduce additional system vulnerabilities as well (e.g., cyber attacks, hacking, and the like). Policymakers and system planners must be mindful of and account for such vulnerabilities in order to not adversely impact grid reliability and incur its associated costs.

---

[54] US Environmental Protection Agency. *Greenhouse Gas Equivalencies Calculator.* Available at: http://www.epa.gov/cleanenergy/energy-resources/calculator.html

Table 5-1

Types of Co-Benefits Potentially Associated With Optimizing Grid Operations

Type of Co-Benefit	Provided by This Policy or Technology?
Benefits to Society	
Non-GHG Air Quality Impacts	Yes
Nitrogen Oxides	Yes
Sulfur Dioxide	Yes
Particulate Matter	Yes
Mercury	Yes
Other	Yes
Water Quantity and Quality Impacts	Yes
Coal Ash Ponds and Coal Combustion Residuals	Typically yes
Employment Impacts	Yes – largely a function of increasing disposable income created by the net savings resulting from displacing higher cost generation that is avoided at the margin
Economic Development	Yes
Other Economic Considerations	No
Societal Risk and Energy Security	Yes
Reduction of Effects of Termination of Service	Maybe
Avoidance of Uncollectible Bills for Utilities	Maybe
Benefits to the Utility System	
Avoided Production Capacity Costs	Yes
Avoided Production Energy Costs	Yes
Avoided Costs of Existing Environmental Regulations	Yes
Avoided Costs of Future Environmental Regulations	Yes
Avoided Transmission Capacity Costs	Yes
Avoided Distribution Capacity Costs	Yes
Avoided Line Losses	Yes
Avoided Reserves	Yes
Avoided Risk	Yes
Increased Reliability	Yes
Displacement of Renewable Resource Obligation	No
Reduced Credit and Collection Costs	Maybe
Demand Response-Induced Price Effect	Yes
Other	No in most cases

6. Costs and Cost-Effectiveness

The costs and cost-effectiveness of approaches to grid optimization vary considerably. The strategies emphasized previously are generally cost-effective or emerging; they can lower overall costs by reducing losses on the system, avoiding the operation of less efficient generation, or operating the system at lower voltage levels to reduce the power delivered to loads. The technologies and rate designs that have enabled these capabilities in the past (e.g., pumped storage, interruptible rates) are being complemented by a new generation of operational enhancements to improve system performance that are enabled by advancing smart grid technology capabilities (e.g., grid-integrated water heaters allow operators to provide ancillary services as well as "store" energy by superheating their contents and time-shifting their load).

One estimate for CVR's cost-effectiveness derives from the Northwest Energy Efficiency Alliance study cited earlier. Voltage reductions ranged from 1 to 3.5 percent. The study found that a one-percent reduction in distribution line voltage provided a 0.25- to 1.3-percent reduction in energy consumption, with most substations seeing results between 0.4 and 0.8 percent.[55] The results further indicate that when voltage reduction is coupled with major system improvements, 10 to 40 percent of the energy savings are from reduced losses on the utility distribution system. That means the majority of savings are from reduced consumption in homes and businesses owing to equipment operating at lower voltage.

Extrapolating these results to the four Northwest states, the Northwest Power and Conservation Council estimates the regional savings potential of CVR combined with distribution system upgrades to be more than 400 average MW by 2029.[56] The Council also estimates that the cost of acquiring those savings is low, with two-thirds of the potential savings achievable at

---

[55] Supra footnote 54.

[56] One average MW equals the energy produced by 1 MW of capacity operating every hour of the year.

a levelized cost of less than \$30 per MWh,[57] compared to average wholesale power costs averaging \$37.53 in 2013.[58]

7. Other Considerations

The approaches discussed previously generally offer a combination of benefits that include enhanced system reliability and reduced or deferred need for additional system investment – and associated risks of overcapitalizing such investments (i.e., creating "stranded" assets) in the rapidly changing power sector.

8. For More Information

Interested readers may wish to consult the following reference documents for more information on optimizing grid operations.

- Cappers, P., MacDonald, J., & Goldman, C. (2013, March). *Market and Policy Barriers for Demand Response Providing Ancillary Services in US Markets.* Lawrence Berkeley National Laboratory. Available at: http://emp.lbl.gov/sites/all/files/lbnl-6155e.pdf
- Cappers, P., Todd, A., & Goldman, C. (2013). *Summary of Utility Studies: Smart Grid Investment Grant Consumer Behavior Study Analysis.* Lawrence Berkeley National Laboratory. Available at: http://emp.lbl.gov/sites/all/files/lbnl-6248e.pdf
- Faruqui, A., Hledik, R., & Palmer, J. (2012, July). *Time-Varying and Dynamic Rate Design.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://raponline.org/document/download/id/5131
- Hurley, D., Peterson, P., & Whited, M. (2013, May). *Demand Response as a Wholesale Market Resource.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://raponline.org/document/download/id/6597
- Lazar, J. (2014, January). *Teaching the "Duck" to Fly.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/6977
- Schneider, K. P., Tuffner F. K., Fuller, J. C., & Singh, R. (2010, June). *Evaluation of Conservation Voltage Reduction (CVR) on a National Level.* Pacific Northwest Labs. Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19596.pdf
- Schwartz, L. (2010, May). *Is It Smart If It Is Not Clean? Strategies for Utility Distribution Systems.* Montpelier, VT: The Regulatory Assistance Project. Available at: www.raponline.org/docs/RAP_Schwartz_SmartGrid_IsItSmart_PartOne_2010_05.pdf
- Porter, K., Mudd, C., Fink, S., Rogers, J., Bird, L., Schwartz, L., Hogan, M., Lamont, D., & Kirby, B. (2012, June 10). *Meeting Renewable Energy Targets in the West at Least Cost: The Integration Challenge.* Western Governors' Association. Available at: http://www.westgov.org/images/dmdocuments/RenewableEnergyTargets2012-13.pdf
- Keay-Bright, S., & Allen, R. (2013, June 24). *Policy Brief: EU Power Policies for PEVs: Accelerating From Here to en Masse.* Montpelier, VT: The Regulatory Assistance Project. Available at: www.raponline.org/document/download/id/6620
- M. J. Bradley & Associates for The Regulatory Assistance Project and the International Council on Clean Transportation. (2013, July). *Electric Vehicle Grid Integration in the United States, Europe, and China: Challenges and Choices for Electricity and Transportation Policy.* Available at: www.raponline.org/document/download/id/6645

9. Summary

There is a long and growing list of system capabilities that can improve grid reliability, increase efficiency, reduce cost, and enhance operating performance. Each of these opportunities to enhance or optimize the grid also typically reduces CO_2 emissions as a result of less – or lower-emitting – generation being needed. This is true at both the level of the transmission grid and the distribution system. With the expansion of the grid to accommodate new types of loads and resources, efforts to identify avenues to manage the cost and performance of the grid will also be required. Advanced communications and automation, including those generally associated with the smart grid, are enabling grid managers to use new, cost-effective strategies for managing the wires. The list of emerging strategies is long, but includes innovative applications of CVR, power factor optimization, phase balancing, the strategic use of electrical and thermal storage capabilities, and focused use of DR capabilities.

---

[57] Northwest Power and Conservation Council. (2010, February). *Sixth Northwest Conservation and Electric Power Plan,* pp. 4–13. Available at: http://www.nwcouncil.org/energy/powerplan/6/default.htm

[58] US Energy Information Administration. (2014, January 8). *New England and Pacific Northwest had largest power price increases in 2013.* Today in Energy. Available at: http://www.eia.gov/todayinenergy/detail.cfm?id=14511