20. Improve Integration of Renewables Into the Grid

1. Profile

State and federal electricity regulation is founded on principles intended to ensure reliable and affordable electric service. Previous chapters in this document demonstrate that renewable resources like wind and solar generation hold tremendous potential for reducing greenhouse gas (GHG) emissions in the power sector. The question electricity regulators face is, "Can we use these tools to meet GHG reduction goals and ensure reliable and affordable electric service at the same time?" Answering this question is sometimes referred to as the "integration challenge," in which "integration" refers to the process of accepting much higher levels of renewable energy and other low-carbon resources without compromising the reliability and affordability of electric service.

This chapter focuses on a suite of policies and mechanisms that can help to ensure continued electric system reliability as the electric system changes to include a higher penetration of variable energy resources (VERs), particularly wind and solar electric generating units (EGUs).[1] These policies and mechanisms do not reduce GHG emissions in and of themselves, but they are necessary complements to many GHG-reducing actions because they enable the electric system to continue to reliably function with a much lower GHG-emitting portfolio of generation resources. However, it is also important to recognize that competing integration strategies often have different GHG footprints, so considering the GHG emissions of the strategies themselves is relevant. For example, natural gas-fired generation can be a powerful tool to help with integration, but sometimes other approaches like energy efficiency, demand response (DR), time-varying rates, and energy storage can meet the electricity system integration requirements with a much lower carbon footprint.

As this chapter demonstrates, this is a time of rapid technology innovation, new market developments, and new thinking about ways to integrate renewable resources. At the same time, the plethora of unique system needs and options to address the integration challenges must be tailored to specific electric systems and regulatory structures. Solutions that work in one locale may be infeasible in another. In addition, choices in one locale can ripple through the interconnected grid, requiring grid operators to carefully coordinate their operations. Air regulators and the energy community will need to work together to understand how to best address integration challenges without imposing unintended consequences.

2. Regulatory Backdrop

This section describes how the federal government and states regulate electric system reliability, provides a basic explanation of what it means to keep the electric system "reliable," and describes the integration challenge in more detail. It concludes with an introduction to a number of policies and mechanisms that can be tailored to the reliability requirements of a specific place.

Who Regulates Reliability?

The Federal Energy Regulatory Commission (FERC) has primary authority to regulate interstate wholesale energy transactions. Market rules and tariffs associated with transmission and competitive wholesale markets mostly fall within FERC's regulatory jurisdiction. Exceptions to FERC's authority exist in states that are islands (Hawaii) or that are electrically separate from the remainder of the continental 48

1 The term "variable energy resource" as used in this chapter refers to any EGU whose output varies over time based on factors that are outside of the control of a system operator and that may be difficult to forecast. Although the VER definition is generic, wind turbines and solar photovoltaic systems, which vary with wind speed and insolation, currently represent virtually all of the installed VERs in the United States. The VER concept is important for any discussion of power sector GHG emissions because VERs are zero-emissions resources.

states (Alaska and parts of Texas), because electricity in those jurisdictions is not traded in interstate commerce. In those exceptional areas, the state Public Utility Commission (PUC) has regulatory authority similar to FERC's over most aspects of transmission tariffs and competitive wholesale markets.

Under FERC direction, the North American Electric Reliability Corporation (NERC) has been given chief responsibility for establishing reliability standards that must be met by all regions throughout the continental United States.[2] NERC delegates its responsibility for monitoring and enforcing reliability standards to eight regional entities, depicted in Figure 20-1. The eight regional entities enforce the standards within their respective boundaries. A detailed discussion of the roles and responsibilities of FERC, NERC, and the regional entities is beyond the scope of this chapter, but can be obtained by visiting the NERC website.

States have independent regulatory authority over the provision of electricity service to retail customers. Typically, investor-owned utilities operate under the jurisdiction of state PUCs, whereas publicly owned utilities and electric cooperatives are governed by local boards. These utilities operate the distribution system and conduct planning for loads and generation resources, but they must do so in a manner consistent with state and local regulations. Many states have instituted policies that encourage or require utilities to procure energy from renewable resources (see Chapter 16), but it is the responsibility of the utilities to integrate those resources in a manner that doesn't compromise reliability. State regulators are pursuing renewable integration by working with system operators and utilities at both the wholesale and retail levels. Policies and approaches vary among the states. Some states favor local development of renewables, whereas others are open to developing remote renewable resources with energy transmitted over long-distance transmission lines.

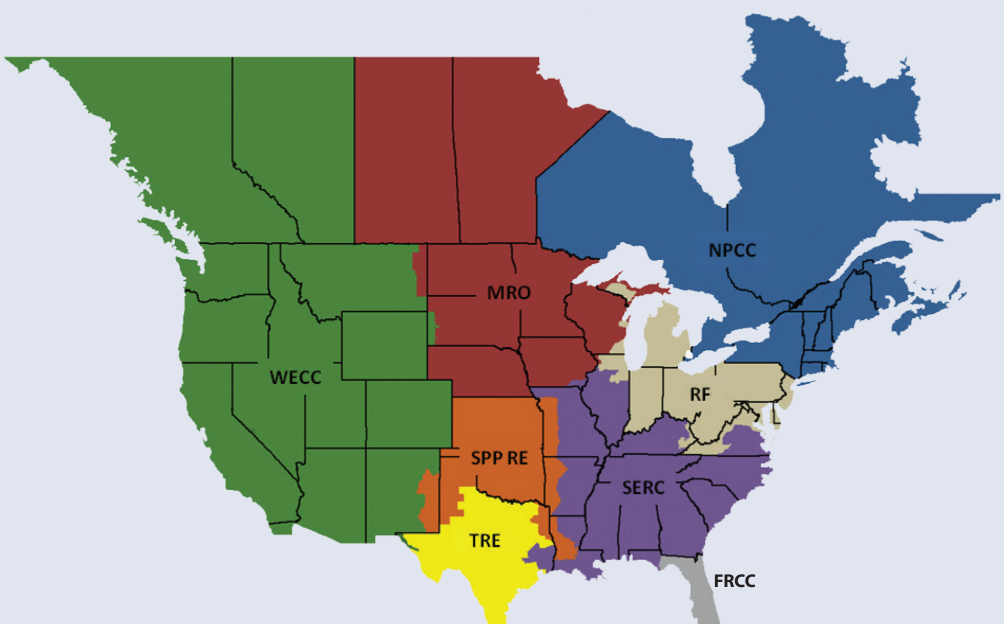
Successfully deploying the various tools and techniques that are effective for integrating renewable resources will require that federal and state regulators, NERC, the regional entities, and utilities cooperate and seek solutions that address fundamental regulatory goals.

What is Energy System Reliability?

Ensuring reliable electric service requires that the supply of electricity almost perfectly matches the demand for electricity at every second of operation in every location.[4] Demand for electricity changes on a second-by-second basis as weather conditions change or as the activities of people and businesses change. Supply of electricity can also change moment-to-moment owing to unexpected generator outages, fuel supply issues, or any number of

Figure 20-1

Regional Entities With Delegated Responsibility for Reliability[3]



FRCC – Florida Reliability Coordinating Council
MRO – Midwest Reliability Organization
NPCC – Northeast Power Coordinating Council
RF – ReliabilityFirst
SERC – SERC Reliability Corporation
SPP – Southwest Power Pool, RE
TRE – Texas Reliability Entity
WECC – Western Electricity Coordinating Council

2 The Canadian government has similarly vested NERC with responsibility for reliability standards in Canada.

3 NERC. Available at: http://www.nerc.com/AboutNERC/keyplayers/Documents/NERC_Regions_Color.jpg.

4 When supply and demand are not equal, the operating parameters of the electric system will deviate from design values. The system can tolerate narrow deviations from design values, but larger deviations can lead to brownouts or blackouts and may damage electrical equipment connected to the grid.

weather-related issues. VERs like wind and solar EGUs are highly dependent on the season and time of day, as well as weather conditions, and thus the supply from these resources can also change quickly. Thus, although the challenge of maintaining supply and demand balance is longstanding, the introduction of VERs adds additional sources of variability.

The US bulk electric grid is divided into dozens of different "balancing authority areas" (BAAs). Within each BAA, a single "balancing authority" acts as the electric system operator and is responsible for balancing supply and demand.[5] Some balancing authorities are large Regional Transmission Organizations or Independent System Operators (ISOs),[6] some are operated by an entity that encompasses the service territories of a number of utilities (e.g., Balancing Area of Northern California), and some are operated by a utility that serves the vast majority of their BAA (e.g., Arizona Public Service and Xcel Energy). The system operator is like an air traffic controller, in that he or she needs to be aware of the electric system status at all times and needs to issue orders to maintain safe operation. In the case of the electric system operator, maintaining awareness involves monitoring the frequency, voltage, power, and availability of system resources at all times. Based on system conditions and available resources, the system operator can issue orders to electricity suppliers and electricity demand managers to adjust supply and demand in order to maintain reliability. The scope of activities performed by system operators is referred to as "balancing."

One aspect of balancing supply and demand involves planning for local and system-wide "resource adequacy" a year or more in advance of real-time operations, as discussed in Chapter 19. Resource adequacy is based on the availability of sufficient generating capacity to meet the anticipated annual and seasonal peak demand, plus an adequate "reserve margin" (i.e., surplus capacity) for unplanned contingencies. Resource adequacy is an essential component of reliability, but is not by itself sufficient to ensure reliability.

System operators must also maintain system balance by issuing orders in much shorter time frames, ranging from one day ahead down to "real time" (i.e., every few seconds). Resources with specific capabilities must be kept in reserve to ensure that supply can adjust to meet demand and maintain system quality in these very short time frames. The services maintained by electric system operators to ensure that supply and demand will always be able to adjust to protect system quality are called "ancillary services." Ancillary services ensure reliability by maintaining frequency, voltage, and power quality on the electric system.

The ancillary services that system operators need are defined primarily by the response speed, the duration of the response, and the time between cycles when the service might be needed. Furthermore, some ancillary services are used routinely during normal conditions, whereas others are only called on during contingency conditions when something has gone unexpectedly wrong on the system (like an unplanned EGU outage). Table 20-1 describes several of the most common types of ancillary services and the capabilities that are required. Another type of ancillary service not shown in Table 20-1 is "black start" capability, that is, the ability of a shut-down EGU to begin operating without drawing electric power from the grid.

Historically, system operators have relied primarily on fossil-fueled or hydroelectric EGUs to provide these ancillary services. Where large hydroelectric EGUs were not available, system operators often relied heavily on natural gas-fired combustion turbines. Renewable technologies with advanced control capabilities and other options like particular DR programs (the subject of Chapter 23) and storage technologies (addressed in Chapter 26) are also capable of providing some of these services, but have been relied on much less frequently.

Most ISOs operate markets that attract competitive bids from qualified resource providers to meet ancillary service needs. Some ISOs and most non-ISO balancing authorities do not operate competitive ancillary service markets but have established other mechanisms for ensuring that

5 Balancing authorities grew out of electric utilities and their commitment to provide reliable power to their customers.

6 There are currently seven Regional Transmission Operators and ISOs in the United States: California ISO (CAISO), Electric Reliability Council of Texas, ISO New England, Midcontinent ISO, New York ISO, PJM Interconnection, and Southwest Power Pool. For a map showing the territories served by these markets, refer to the ISO/RTO Council at http://www.isorto.org/. The distinction between Regional Transmission Operators and ISOs is subtle and, for the purposes of this chapter, not particularly relevant. For simplicity, the remainder of this chapter refers to either type of organization as an ISO. All generation and load is under the management of a balancing authority, but not all balancing authorities are members of ISOs.

Table 20-1

Description of Different Ancillary Services[7]

Service	Response Speed	Duration	Cycle Time	Price Range* (Average, Max) $/MW-hr
Normal Conditions				
Frequency Regulation	Online resources, on automatic generation control, that can respond rapidly to changes in frequency.			
	<30 seconds	Seconds to Minutes	Seconds to Minutes	
Regulating Reserve	Online resources, 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.			
	4 Seconds to 5 minutes	Minutes	Minutes	\$35-\$40 \$200-\$400
Load Following	Similar to regulation but slower. Bridges between regulation service and hourly energy markets. This service is performed by the real-time energy market in regions where such a market exists.			
	~10 minutes	10 min to hours	10 min to hours	-
Contingency Conditions				
Spinning Reserve	Online generation, synchronized to the grid, that can increase output immediately in response to a major generator or transmission outage and can reach full output within 10 min.			
	Seconds to <10 min	10 to 120 min	Hours to Days	\$7-\$7 \$100-\$300
Non-Spinning Reserve	Same as spinning reserve, but need not respond immediately; resources can be offline but still must be capable of reaching full output within the required 10 min.			
	<10 min	10 to 120 min	Hours to Days	\$3-\$6 \$100-\$400
Replacement or Supplemental Reserve	Same as spinning reserve, but with a 30-60 min response time; used to restore spinning and non-spinning reserves to their pre-contingency status.			
	<30 min	2 hours	Hours to days	\$0.4-\$2 \$2-\$36

ancillary services are made available to the system operator. In some areas, the utility that operates the balancing authority self-provides all ancillary services. In others, the balancing authority requires each load-serving entity that operates within its boundaries to provide its pro rata share of some or all of the ancillary services needed by the system operator, and the system operator dispatches those services as necessary.

What is the Renewable "Integration Challenge"?

The United States has seen tremendous growth in wind and solar power over the past decade, as indicated in Figures 20-2 and 20-3. In the first half of 2014, more than half of all newly installed electric capacity in the United States came from solar power.[8]

This growth in VERs is having a positive impact on power sector GHG emissions, but it also creates new challenges for electric system operators. It has become common to discuss the challenge of meeting variations in supply arising from VER production as the "Integration Challenge." Air regulators who hope to see even greater use of renewable energy to reduce GHG emissions need to understand the different dimensions of this integration challenge and some of the potential solutions.

Because the output of wind and solar EGUs cannot be perfectly predicted or controlled, electric system operators need to manage the system around whatever output those EGUs produce or require the VERs to provide their own ancillary services as a condition of interconnection. One way to visualize this is to think not in terms of the gross demand for electricity, but in terms of a "net demand" or "residual demand" that remains after the output of VERs is subtracted from gross demand. As the penetration of VERs on the grid

7 Hurley, D., Peterson, P., & Whited, M. (2013). *Demand Response as a Power System Resource.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/6597

8 Solar Energy Industries Association. (2014). *Solar Energy Facts: Q2 2014*. Available at: http://www.seia.org/research-resources/solar-market-insight-report-2014-q2

Figure 20-2

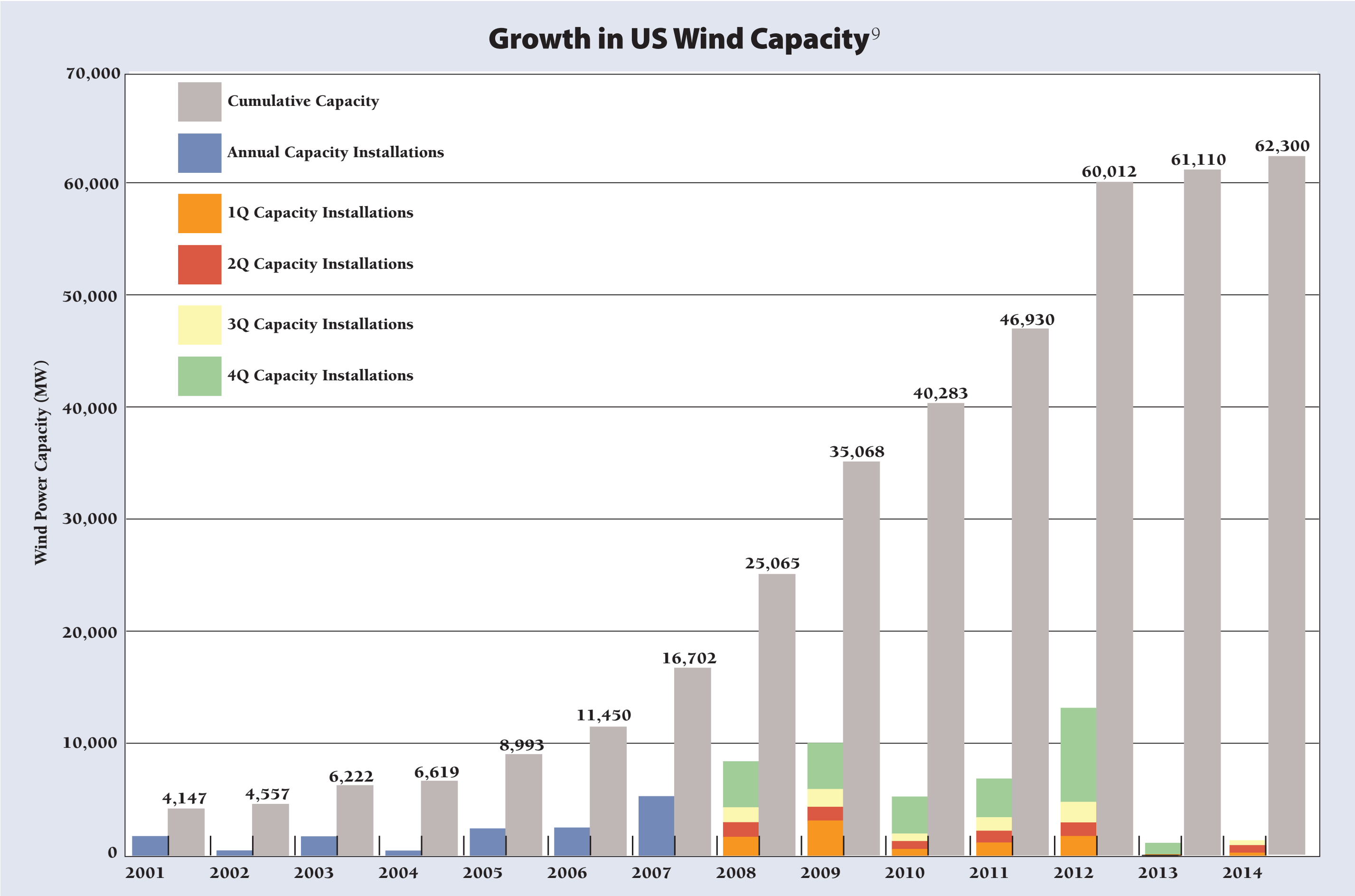
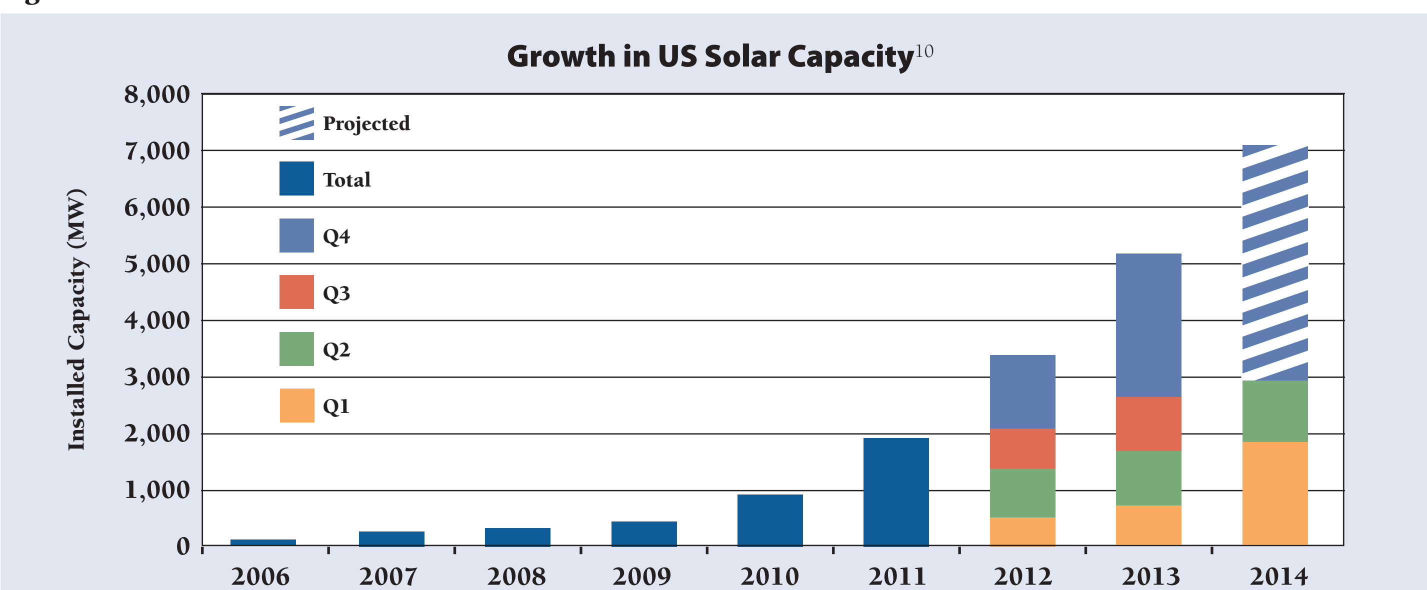


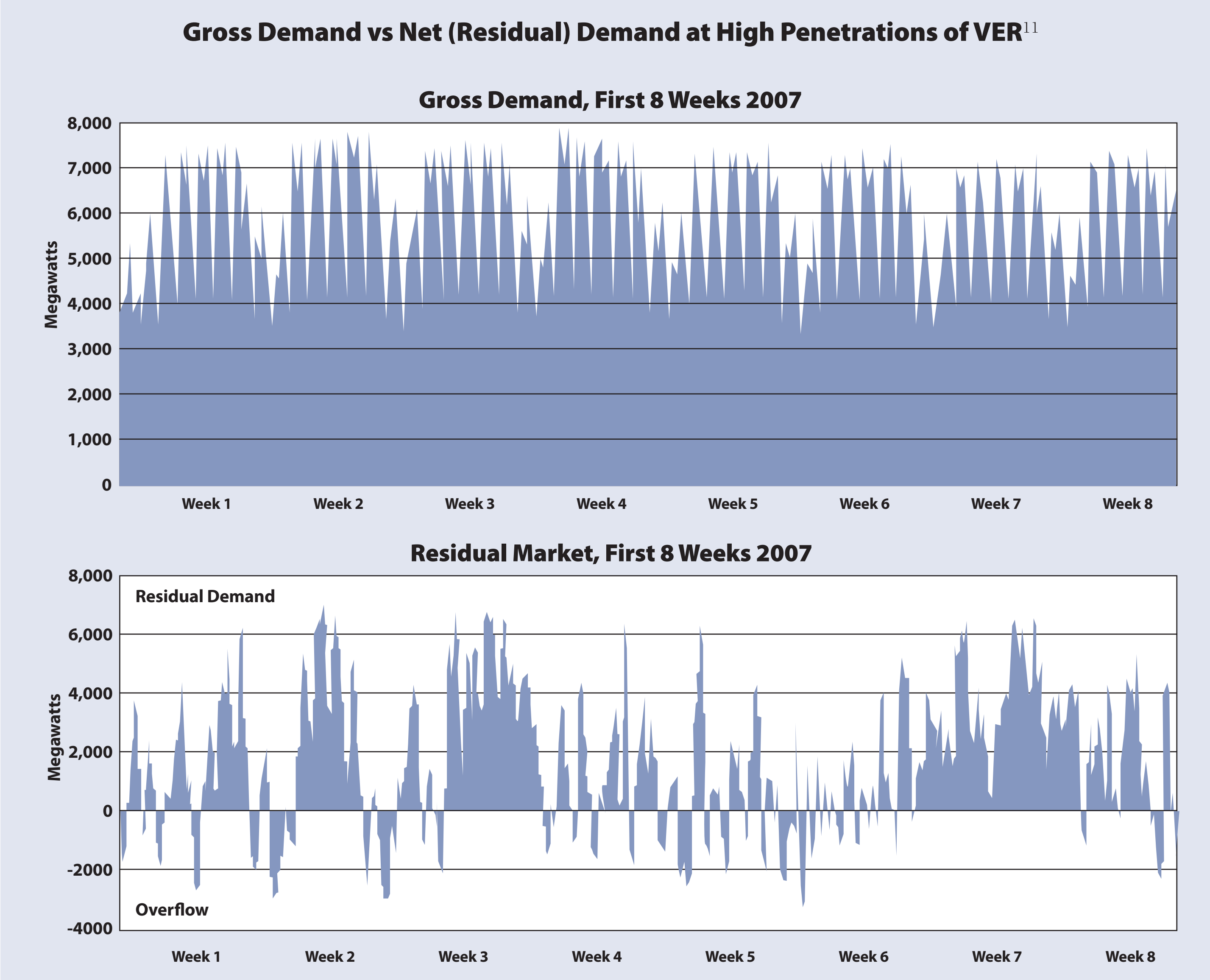
Figure 20-3



9 American Wind Energy Association. (2014). *US Wind Industry Third Quarter 2014 Market Report*. Available at: http://www.awea.org/3Q2014

10 Supra footnote 8.

Figure 20-4



increases, the differences between operating the system to meet gross demand and operating the system to meet net demand become dramatic. These differences are illustrated in Figure 20-4, which shows an actual example of gross and net (residual) demand during an eight-week period in Denmark, where VERs were already producing more than 20 percent of energy on an annual basis and producing more than enough energy to meet total demand during some periods.

What Figure 20-4 shows is that the need for ancillary services that keep the system in balance is very different and much greater as the penetration of VERs increases. When the penetration is sufficiently high, as in the example, there will even be times when the output of VERs exceeds demand. In those cases, the system operator will need to be able to export the surplus energy to an adjoining system, temporarily *increase* demand (e.g., through a DR program that shifts energy consumption from times of high net demand to times of low net demand), rely on storage, or curtail the output of the VERs. According to a National Renewable Energy Laboratory (NREL) report, system operators in the United States are commonly forced to curtail roughly one to four percent of annual wind energy

11 Hogan, M., & Gottstein, M. (2012, August). *What Lies "Beyond Capacity Markets"? Delivering Least-Cost Reliability Under the New Resource Paradigm. A "straw man" proposal for discussion.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/6041

output.[12] From the perspective of reducing GHG emissions, curtailing the output of zero-emissions VERs is a very undesirable outcome.

Integrating new resources in a way that maintains reliable system operation is not unique to VERs. In fact, the legacy of a system dominated by very large, inflexible resources contributes to the integration challenge, and the addition of new, large, inflexible EGUs has historically required extensive system planning. However, the variable and weather-dependent nature of some renewable resources presents a different kind of integration challenge. Electric system operators will have to adopt more flexible operational practices and they will need access to more flexible resources in order to maintain system balance as the quantity of VERs grows. System operators will need to work with states and the energy industry to choose integration approaches that provide the best solution, develop ways to implement them, and identify the necessary mechanisms to pay for them in a fair and non-discriminatory way.

The introduction of greater variability in net demand underscores the need to ensure that system reserves have adequate flexibility. Table 20-1 defined several types of reserves but a flexibility reserve category does not exist in most places. The "traditional" capacity mechanisms discussed in Chapter 19 focus only on a simple version of resource capacity, aimed exclusively at procuring enough capacity to meet peak demand during a relatively limited number of hours in the year, irrespective of the EGUs' operating capabilities in other hours. This traditional definition of capacity has historically determined the reserve requirement. These traditional mechanisms are not designed to elicit the operation of or investment in capacity with the flexible capabilities that will be required with increasing frequency, and at multiple times of the day or year, as the share of VERs in the power mix increases. Although most system operators do not currently offer an ancillary service called "flexibility service," the increasing presence of VERs in the portfolio of resources is likely to cause such a service to be offered in an increasing number of electric systems. Changes to capacity markets and changes to ancillary services are needed.

Fortunately, different policies and mechanisms are being tested throughout the country and some are available now to help states meet the new integration challenge with a minimal carbon footprint. States, working with many regulatory and market stakeholders, can adopt long-term strategies that allow low-carbon resources to meet system flexibility needs, as well as smart planning options that limit the amount of variability present on the system. Transitional issues are expected to occur, largely because the system already has an extensive fleet of conventional resources and VERs with established operating parameters and contracts that were designed before integration challenges were fully recognized. However, new technologies, market rules, and payment methods are being worked out to address integration challenges. Solutions will need to be tailored to the different resource mixes, grid and infrastructure designs, as well as the market designs and regulatory requirements for both state and regional solutions. We now briefly introduce several categories of actions that are being tested or used throughout the country.

Using Low-Carbon Flexible Resources

Electricity systems have traditionally relied on fossil resources like gas-fired combustion turbines to provide quick-start or quick-adjusting capabilities needed for some ancillary services and to provide flexibility service, but other low-carbon resources can also provide these capabilities. For example, DR resources, storage, distributed solar resources with smart inverters, and wind resources equipped with advanced control technologies (refer to text box) can each offer dispatchable ancillary services and each contribute to increased system flexibility. It is important not to overlook the capabilities of these low-carbon resources in helping to meet the integration challenge. Retrofitting of some VERs to take advantage of these services may be possible, whereas others will become available as new manufacturing, permitting, or interconnection rules are revised or new rules established. Flexible resources are discussed in more detail later in this chapter.

12 Bird, L., Cochran, J., & Wang, X. (2014). *Wind and Solar Energy Curtailment: Experience and Practices in the United States.* National Renewable Energy Laboratory. Available at: http://www.nrel.gov/docs/fy14osti/60983.pdf

Advanced Control Technologies for Wind Turbines[13]

Wind power is "variable" in the sense that maximum available power varies over time (variability), it cannot be predicted with perfect accuracy (uncertainty), and it is not synchronized to the electrical frequency of the power grid and is generally unresponsive to system frequency (asynchronicity). However, Active Power Controls for wind turbines are being developed to address variability, uncertainty, and asynchronicity. The New York ISO has been calling on wind power with just five minutes' notice to relieve congestion on its transmission system since 2008 and several other ISOs have followed suit. These regions have found the tremendous capability that wind power can provide in controlling its output (within the range of what is possible at any time based on wind speeds) to be extremely beneficial. Other Active Power Control capabilities being demonstrated today include synthetic inertia, Primary Frequency Control, and Automatic Generator Control. Proven experience and ongoing demonstrations indicate wind power's potential to economically support power system reliability by adjusting power output. These adjustments can mitigate the need to completely curtail a turbine or offer opportunities to provide ancillary services that may be more valuable than energy.

Using Smart Low-Carbon Integration Planning

The amount of variability in net demand that needs to be accommodated by the system operator can also be mitigated with smart, clean energy strategies that smooth out demand on a regional and local basis. On a regional basis, ten specific tools available for meeting the integration challenge have been illustrated in a paper from The Regulatory Assistance Project, *Integrating Renewables.*[14] (See text box that follows.) Although a detailed description of each strategy is beyond the scope of this short chapter, the strategies involve investing in more intelligent grid systems, modifying regional operational practices to take advantage of a smarter grid, and introducing more cooperation among electric system operators to leverage regional resource diversity and the capabilities of existing resources.

Ten Strategies for Meeting the Integration Challenge at Least Cost

1. Intra-Hour Scheduling
2. Dynamic Transfers
3. Energy Imbalance Markets
4. Improve Variable Generation Forecasting
5. Increase Visibility of Distributed Generation
6. Improve Reserves Management
7. Retool Demand Response to Meet Variable Supply
8. Utilize Flexibility of Existing Plants
9. Encourage Flexibility in New Plants
10. Improve Transmission for Renewables

Increasing the visibility of distributed generation (DG) (strategy 5) and retooling DR (strategy 7) will allow the system operator to anticipate, address, and in some cases reduce local net demand variability. Additional strategies like using time varying prices and energy storage technologies are also available to smooth net demand.

An example of how energy efficiency, DR, storage, pricing, and DG can be combined to smooth local net demand is illustrated in another Regulatory Assistance Project publication, *Teaching the Duck to Fly.*[15] The text box below summarizes the ten local strategies illustrated in that publication; each is fully explained in the paper. For now it is sufficient to say that taking actions like investing in specific types of energy efficiency, adapting how solar energy panels are used, using time-varying pricing, installing storage, and taking advantage of underutilized DR resources can be powerful tools for meeting the new integration challenge. Some of these strategies are already underway in some places, and others are emerging as a

13 Ela, E., Gevorgian, V., Fleming, P., Zhang, Y. C., Singh, M., Muljadi, E., Scholbrook, A., Aho, J., Buckspan, A., Pao, L., Singhvi, V., Tuohy, A., Pourbeik, P., Brooks, D., & Bhatt, N. (2014, January). *Active Power Controls from Wind Power: Bridging the Gaps.* National Renewable Energy Laboratory, University of Colorado, and Electric Power Institute. Available at: http://www.nrel.gov/docs/fy14osti/60574.pdf

14 Baker, P., Bird, L., Buckley, M., Fink, S., Hogan, M., Kirby, B., Lamont, D., Mansur, K., Mudd, C., Porter, K., Rogers, J., & Schwartz, L. (2014, December). *Renewable Energy Integration Worldwide: A Review.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org

15 Lazar, J. (2014). *Teaching the "Duck" to Fly.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/6977

Ten Strategies to Align Loads to Resources

1. Targeted Energy Efficiency
2. Orient Solar Panels
3. Use Solar Thermal With Storage
4. Manage Electric Water Heat
5. Require New Large Air Conditioners to Include Storage
6. Retire Older Inflexible Power Plants
7. Concentrate Rates Into "Ramping" Hours
8. Deploy Electricity Storage in Targeted Locations
9. Implement Aggressive Demand Response Programs
10. Use Inter-Regional Exchanges of Power

straightforward evolution of current practice, but some will require new procedures, monitoring technologies and regulatory approval. The amount of time and effort required to implement the strategies is location-specific, and those specifics should be considered as one decides what combination of strategies can accommodate the greatest amount of variable energy while meeting reliability goals at the most reasonable cost.

Regulators need to ensure through their oversight of utilities and ISOs that any low-carbon resources that have flexibility and ancillary services capabilities are eligible to offer these capabilities to BAA operators. Regional and local system operations practices also need to evolve so that low-carbon strategies can be used to mitigate variability in net demand.

3. State and Local Implementation Experiences

As discussed in Chapters 16 and 17, many states are choosing to implement policies that support increased adoption of distributed and large-scale renewable energy, and as the costs of these resources continue to decline, the opportunity for relying on them more heavily to meet carbon reduction goals will grow. These policies can be very effective in promoting carbon reduction, but increasing levels of variable resources will affect how electricity systems are operated. The level of variable energy that can be accommodated on electric systems without significant changes in practices varies, but electricity system operators throughout the country will face an integration challenge at some point, and thus every state will eventually focus on using new technologies, improving operating practices, and improving ancillary service mechanisms. Vertically integrated utilities are affected by integrated resource planning processes, and even some utilities that operate in a competitive market footprint seek authorization from their state PUC to procure new resources from a third party in order to ensure adequate availability of resources. These requests by utilities to build or buy new resources are often motivated by the need to have adequate resources to ensure reliability. Although most utility requests focus on ensuring adequate capacity to meet peak demand periods, it has always been true that local reliability issues associated with the need to maintain voltage or frequency are sometimes offered by utilities as a justification to build or buy new resources. With increasing VER penetration, utilities have also offered the need to integrate renewables as a justification for building or buying new resources. Although some new fossil resources may be required to integrate renewables, many solutions to ensure reliability in the presence of high penetration of VERs at least-cost exist or are under development.

Recently, some states with retiring large central-station resources, such as large coal or nuclear plants, have heard from their utility or system operator that these EGUs provide system inertia that is helpful in maintaining reliability, and the effect of the loss of those plants on inertia needs to be taken seriously.[16] But at the same time, studies in the Electric Reliability Council of Texas, California, PJM, and in the Western Interconnection each affirm that penetrations of VERs up to 35 percent can be

16 Synchronous generators, including coal-fired and nuclear power plants, rely on massive, rapidly spinning rotors to generate electricity. In the first few seconds following the unexpected loss of power from a large generating unit, the frequency of electricity on the entire grid begins to drop. When the frequency drops, all of that spinning mass will begin to slow down as an inherent and automatic physical reaction, but as it does so it will also release some of its inertial energy to the grid. This temporarily and partially mitigates the loss of power in what is known as synchronous inertial frequency response or simply "inertia." If there is enough inertia in the system, the frequency will remain at an acceptable level until slower forms of frequency response such as governors can be activated. NREL is investigating this issue in Phase 3 of the Western Wind and Solar Integration Study, and the results of that study are expected to illuminate whether there is indeed a problem with reduced system inertia and, if so, how large the problem is.

accommodated without compromising reliability, and even higher levels of renewables have been shown to be technically feasible while maintaining reliability.[17,18] Getting to the bottom of these reliability concerns is vital, and integration strategies that meet the reliability challenge posed will need to be tailored to local circumstances to ensure the challenge is met at a reasonable cost.

As noted previously, the integration challenge requires utilities and system operators to think in terms of system flexibility. Most of the ten strategies for meeting the integration challenge at least cost (listed earlier) have been implemented at least to some degree in a variety of locations and have helped to increase system flexibility to more easily and cost-effectively incorporate the resources available to system operators. State and local implementation experiences, as well as descriptions of changes that may be needed but have not yet happened, are provided below.

Intra-Hour Scheduling

With more varied sources and sizes of generation, tighter control of the system is needed even with improved forecasting to reduce the uncertainty associated with VERs. Sub-hourly dispatch refers to the practice of changing generator outputs at intervals less than an hour. Intra-hour scheduling refers to the practice of changing transmission schedules at intervals less than an hour. Because most generation is delivered with transmission, sub-hourly dispatch of generation can only be effectively used if transmission schedules can be modified within the hour. Thus, sub-hourly dispatch and intra-hour scheduling are "hand-in-glove" practices that are fundamentally interdependent. Sub-hourly dispatch and intra-hour scheduling reduce the quantity of balancing reserves required and thus can provide significant cost-saving benefits to consumers. Grid operators can also benefit from greater access to more generation and demand resources that ease the challenge of integrating variable generation. Additional benefits include lower energy imbalance costs for all generators, including VERs, and greater access to transmission if scheduling and dispatch are effectively combined.

In the competitive wholesale markets operated by ISOs, system operators dispatch generation at five-minute intervals and coordinate transmission with dispatch. In contrast, most transmission outside of the ISO territories (in the Western and Southeastern United States) is scheduled in hourly intervals, which makes the integration challenge more difficult.[19] However, because of existing contracts and regulatory treatment of certain generation assets, many resources are self-scheduled by the owner and do not make themselves available for re-dispatch by the system operator except in times of transmission constraints or system emergencies.

Dynamic Transfers

A "dynamic transfer" is a coordinated transfer of firm energy between BAAs. In the absence of dynamic transfers, all energy transferred between BAAs operates on a "static" schedule. A static schedule is submitted 20 to 75 minutes before the onset of the hour for which the schedule will apply, and it is not adjusted during that hour. With dynamic transfers, energy can be scheduled more than an hour ahead or within the hour down to intervals as brief as four seconds.

The Sutter Energy Center (which is in California but outside of the CAISO BAA boundary) is an example where dynamic transfer is being used by an ISO to support operating reserve, regulation, energy imbalance, and load-following services. The BC Hydro System in British Columbia and the Hoover Dam in Nevada are other examples of resources that provide regulation service,

17 See the following document for summaries and citations to major studies all showing that penetrations of this size do not propose insurmountable problems to grid reliability. Linvill, C., Midgen-Ostrander, J., & Hogan, M. (2014, May) *Clean Energy Keeps the Lights On.* Montpelier, VT: The Regulatory Assistance Project. Available at: http://www.raponline.org/document/download/id/7175

18 National Renewable Energy Laboratory. (2014, September). *Renewable Electricity Futures Study.* Available at: http://www.nrel.gov/analysis/re_futures/ McKinsey & Company, KEMA, The Energy Futures Lab at Imperial College London, Oxford Economics, & the ECF. (2010, April). *Roadmap 2050: A Practical Guide to a Prosperous, Low-Carbon Europe. Volume 1: Technical and Economic Analysis, Full Report.* Available at: http://www.roadmap2050.eu/reports

19 Utilities outside of ISO territories are equally capable of intra-hour scheduling, but traditionally have not seen the need for it as they have been dependent primarily on dispatchable resources that they themselves own. As these utilities begin to rely more on variable resources and on purchased power, intra-hour scheduling gains importance.

energy imbalance service, and load-following service to proximate and remote BAAs. Dynamic transfer can also be used to support renewable or VER import scheduling. Examples of renewable resources that are dynamically scheduled to serve a remote BAA include: Argonne Mesa Wind in New Mexico; Copper Mountain Solar in Nevada; Arlington Valley Solar in Arizona; CE Turbo Geothermal in California; and Hudson Ranch Geothermal in California.[20]

Energy Imbalance Markets

Energy imbalances are the difference between advance generation schedules and what is actually delivered within the scheduled period. The scheduled period may be an hour ahead or may be as little as five minutes ahead.

In November 2014, CAISO and PacifiCorp launched a regional real-time energy imbalance market (EIM). It uses an automated system to dispatch resources across multiple BAAs in real time for use as short-term balancing resources to ensure that supply matches demand. This helps reduce costs by broadening the pool of low-cost resources that can be accessed to balance the systems. The market design is based on a conceptual proposal from CAISO that will provide ease of future entry for other balancing authorities. The EIM makes the CAISO five-minute market available to other entities so their resources can be economically and automatically dispatched in real time, thus optimizing the level of available resources and reducing the quantity of required reserves. The Northwest Power Pool is also developing a platform for facilitating intra-hour exchanges among BAAs.[21]

Improve Variable Generation Forecasting

Variable generation forecasting uses weather observations, meteorological data, Numerical Weather Prediction models, and statistical analysis to generate estimates of wind and solar output to reduce system reserve needs. Such forecasting also helps grid operators monitor system conditions, schedule or de-commit fuel supplies and power plants in anticipation of changes in wind and solar generation, and prepare for extreme high and low levels of wind and solar output. Federal and state research and development has brought VERS forecasting to the level it can be today, as there are so many variables and measurements that need to be taken into account. For example, wind speeds depend on the height of the turbine, the variety of the terrain, and the efficiency of the turbine. Continued advances in forecasting efforts are anticipated.

Table 20-2 presents general wind forecast errors in the United States by Mean Absolute Error for hour-ahead and day-ahead forecasts, by individual wind plant and for all wind plants in a large region, as well as forecast errors by energy and by capacity.[22] The table presents two important findings: (1) forecast errors for a single wind plant are larger than for multiple wind plants in a region; and (2) forecast errors are smaller the closer to the time generation serves demand.

Table 20-2

Average Wind Forecast Error by Time Frame[23]

	Forecast Error	
	Single Plant	**Region**
Hour-Ahead		
Energy (percent actual)	10 to 15 percent	6 to 11 percent
Capacity (percent rated)	4 to 6 percent	3 to 6 percent
Day-Ahead		
Hourly Energy (percent actual)	25 to 30 percent	15 to 18 percent
Hourly Capacity (percent rated)	10 to 12 percent	6 to 8 percent

20 For more information on dynamic transfers, see: Coffee, K., McIntosh, J., Hoffman, K., & Nagel, J. (2013). *Dynamic Transfers for Renewable Energy in the Western Interconnection.* Montpelier, VT: The Regulatory Assistance Project. Available at: www.raponline.org/document/download/id/6603

21 The EIM is currently limited to intra-hour imbalances and thus covers a limited set of resources. The EIM is an incremental addition to a much larger set of dispatch rules for energy, capacity, and ancillary services.

22 The Mean Absolute Error takes the absolute values of the individual wind forecast errors divided by the predicted or reference value. Another measure, the Root Mean Square Error, involves obtaining the total square error first, dividing by the total number of individual errors, and then taking the square root.

23 Marquis, M., Wilczak, J., Ahlstrom, M., Sharp, J., Stern, A., Smith, J. C., & Calvert, S. (2011). Forecasting the Wind to Reach Significant Penetration Levels of Wind Energy. *Bulletin of the American Meteorological Society,* 92(9), pp. 1159-1171. Available at: http://uvig.org/wp-content/uploads/2013/01/BAMS-Wind_Forecasting.pdf

Larger balancing areas can smooth the variability of wind and solar output through geographic diversity. In turn, that reduces forecasting errors. Generally, forecast errors can be reduced 30 percent to 50 percent by aggregating multiple wind plants as compared to wind forecast errors of individual or geographically concentrated plants.[24] As an example, combining the control areas of Eastern and Western Denmark added about 100 kilometers, and resulted in the total cancelling out of day-ahead wind forecast errors at least one-third of the time.[25]

Increase Visibility of Distributed Generation

Distributed generation operating on the customer side of the meter is commonly "invisible" to system operators. These generators must be interconnected by a utility to ensure they operate safely. But once they are interconnected, unless advanced two-way metering is installed, combined with devices such as smart inverters with communication capabilities, these generators do not usually have the capability to respond to dispatch commands from a system operator. This is particularly true for behind-the-meter resources connected at customer sites, which are netted out with customer load.

Solar DG systems may also be geographically concentrated, and can increase concerns about local over-voltages and distribution equipment overload. These issues are currently dealt with during interconnection. Although this has generally posed little problem in the past and is not a problem in places with modest DG adoption, the projected rapid growth of DG in some places has prompted

Adding Smart Inverters to Interconnection Standards in California[26]

Achieving the state's renewable energy goal requires a fundamental paradigm shift in the technical operation of the distribution system in California. The technical operating standards set out in California's interconnection rules accommodate small amounts of power flows from distributed energy resource (DER) systems, but have not adequately coped with the expected large amounts of DG in a way that supports the paradigm shift in distribution system operations. Technical steps for the paradigm shift were needed as California approached greater numbers of installed DER systems, higher penetrations on certain circuits, and the implementation of a smart distribution system that optimizes interconnected resources were necessary. On December 18, 2014 California took a step forward in making these changes when the California PUC approved advice letters directing the utilities to use inverters with autonomous controls.

The inverter component of DER systems (a.k.a. I-DER) can be programmed to support distribution system operations.[27] Collectively, these programmable functions are called "smart inverter functionalities." Smart inverter functionalities are separated into three groups: autonomous functionalities, communications capabilities, and advanced inverter functionalities that sometimes utilize communications. As California approaches greater numbers of installed DER systems and higher penetrations on certain circuits, enabling the use of smart inverter functionalities will assist with the transition to smarter distribution grid operation that optimizes the DG of interconnected resources.

24 Lew, D., Milligan, M., Jordan, G., & Piwko, R. (2011, April). *The Value of Wind Power Forecasting.* Golden, CO: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/docs/fy11osti/50814.pdf

25 Holttinen, H., & Hirvonen, R. (2012). Power System Requirements for Wind Power. In T. Ackermann (Ed.), *Wind Power in Power Systems* (pp. 143-165). West Sussex, England: John Wiley & Sons, Ltd. Available at: http://onlinelibrary.wiley.com/doi/10.1002/9781119941842.ch6/summary

26 Adapted from: California Energy Commission and California Public Utilities Commission. (2013, December). *Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources. Smart Inverter Working Group Recommendations.* Executive Summary, pp. 1-2. Available at: http://www.energy.ca.gov/electricity_analysis/rule21/documents/recommendations_and_test_plan_documents/CPUC_Rule_21_Recommendations_v7.docx

27 The Smart Inverter Working Group has used the term "I-DER system" to propose that the inverter-based DER systems are able to take advantage of recent technological advances to actively enhance power system operations.

state and local regulatory agencies to begin evaluating whether system upgrades will be necessary and how these system upgrade costs will be allocated.

With the rapid projected growth of DG, the lack of visibility for system operators is becoming cause for concern. System operator and utility concerns can be divided into the impact of DG on load forecasting and the potential for large amounts of DG to be dropped from the grid by system operators in response to system disturbances. However, it should be noted that some solar photovoltaic inverters can autonomously react to local system variations and others are capable of controlling active and reactive power. Various regions or countries are requiring or thinking of requiring smart inverters, because they allow operators to maintain visibility and control in real time. With "dumb" inverters, curtailment is the blunt instrument used when disturbances occur, so installing smart inverters reduces curtailment events and can enable safe low-voltage ride-through, which is beneficial to the electric system and to the DG owner.

Improve Reserves Management

Higher penetrations of wind and solar resources increase the variability and uncertainty of the net load served by the system, either causing the existing level of balancing reserves to be called upon more frequently or increasing the required quantity of balancing reserves. However, as described in this chapter, the need for additional balancing reserves can be reduced through operational mechanisms to manage reserves more efficiently.

Retool Demand Response to Meet Variable Supply

Where the fuel that drives a growing share of supply is beyond the control of system operators, as is the case with wind and solar energy, it is valuable to have the ability to shift load up and down by controlling water heaters, chillers, and other energy-consuming services. Time-varying rates can provide for beneficial load shape modification, and additional integration benefits can be achieved by implementing either direct control of the load or preprogrammed responses to real-time prices. Experience suggests that DR can be a key component of a low-cost system solution for integrating variable generation. DR also provides many other benefits, including increased customer control over bills, more efficient delivery of energy services, and a more resilient power system. Defining DR well is important, as in some places inefficient, high-emitting fossil-fueled backup generators qualify as DR resources, and increased use of these resources can be counterproductive to meeting climate and air quality goals. For specific examples of state and local implementation of DR programs, refer to Chapter 23.

Utilize Flexibility of Existing Plants

Output control range, ramp rate, and accuracy — along with minimum run times, off times, and startup times — are the primary characteristics of generating plants that determine how nimbly they can be dispatched by the system operator to complement wind and solar resources. In addition, some generation can provide local reactive power. There are economic tradeoffs between plant efficiency, emissions, opportunity costs (the revenue lost when a generator foregoes energy production in order to provide flexibility), capital costs, and maintenance expenses, but there can be cost savings associated with making the most of the fleet we already have.

The first step in maximizing the use of existing generation is to encourage market mechanisms that recognize the value of flexible generation capabilities. In the United States, there has been a tendency to focus on capacity markets (see Chapter 19) to ensure resource adequacy, but it is clear that we need to move beyond capacity markets so that the full range of generation capabilities that have value become expressed. Some ISOs have taken steps in that direction, but more could be done. Once capabilities are properly valued, use of the existing fleet will be optimized and the value of retrofitting existing generation will be clarified. Although selecting technologies that are inherently flexible will be possible over time, some plants can be retrofitted to increase flexibility by lowering minimum loads, reducing cycling costs, and increasing ramp rates, and for some plants this will be a cost-effective alternative to commissioning a new facility.

Encourage Flexibility in New Plants

Traditionally, system operators relied on controlling the output of power plants — dispatching them up and down — to follow fairly predictable changes in electric loads. First, based on load forecasts, generating plants were scheduled far in advance to operate at specified output levels. Then, in real time, these generators would automatically or manually adjust their output in response to a dispatch signal sent by the system operator as needed to balance supply with actual load.

With an increasing share of supply from VERs, grid operators will no longer be able to control a significant portion of generation capacity. At the same time, renewable resources are among the most capital-intensive and lowest-cost to operate. Once built, typically the least-cost approach is to run them as much as possible. Therefore, grid operators will need dispatchable generation with more flexible capabilities for following the less predictable net demand.

New dispatchable generation will need to frequently start and stop, change production to quickly ramp output up or down, and operate above and below standard utilization rates without significant loss in operating efficiency. Flexible resources that can meet increased system variability needs with high levels of wind and solar generation will enable more efficient system operation, increased use of variable zero-cost resources, and lower overall system operating costs.

A significant challenge is establishing what generator capabilities are needed to maintain reliable electric service in the operating and planning time frames and then establishing markets to communicate the value of these attributes to supply- and demand-side resource providers. Once these flexibility capabilities are defined, a further challenge lays in assessing how much flexible capacity already exists and how much will be needed — and when. Resource planning and procurement processes typically have not been focused on flexible capability. New metrics and methods are needed to assess flexibility of resource portfolios and resource capabilities needed in the future. However, FERC and many states have been experimenting with pilots and concepts of what might be workable approaches. States will benefit from those experiments and may wish to undertake their own investigations on this tricky issue. In the meantime, a potentially helpful interim step would be for states to review whether their current policies in any way encourage or promote inflexible capacity, and if so to consider modifications.

Improve Transmission for Renewables

Lack of transmission can be a significant impediment to new utility-scale renewable energy plants, as the locations of renewable energy plants are limited to areas with sufficient renewable energy resources, which tend to be located in more remote areas, away from load centers. Typically, transmission planning is an established, multiyear process that takes into account the impact of various alternatives on the grid. After a transmission line makes it through the planning process a route must be permitted. The whole process can take up to a decade to complete and can involve multiple federal and state agencies. This issue is explained in detail in Chapter 18, along with some potential solutions.

4. GHG Emissions Reductions

The strategies described in this chapter do not directly reduce GHG emissions. Rather, these strategies indirectly reduce GHG emissions by reducing the curtailment of existing, zero-emissions EGUs and facilitating the deployment of more zero-emissions EGUs. The potential GHG emissions reductions that can be achieved through greater deployment of clean energy technologies are detailed in Chapters 6, 16, and 17. Effective VER integration policies and mechanisms will increase the likelihood that the full potential of those strategies is reached, whereas ineffective integration will undermine those strategies.

Ensuring reliability by effectively using supply- and demand-side resources to maintain system balance is a necessary condition for supporting any portfolio of generation resources. Maintaining system balance with a generation portfolio that has a high proportion of VERs will require evolution of operating practices and addition of some ancillary service capabilities. Such a portfolio may also require the explicit recognition of new categories of ancillary services. For example, recent studies of areas with high penetrations of solar generation indicate that having resources that can support a sustained ramp-down of dispatchable generation in the morning and a sustained ramp-up of resources through the evening hours is likely required to ensure reliability. (See the Duck Curve Text Box on page 20-9). Therefore, reducing GHG emissions by transitioning to a high variable-energy portfolio will depend on the proper development of the necessary ancillary resources, and regulators should be aware that enjoying the carbon reduction benefits of increased VERs depends on these ancillary service investments.

At the same time, it is important to recognize that low-carbon resources can provide some of the capacity reserves and ancillary resources required by a portfolio high in variable renewable energy. As previously noted, there are operational changes (such as improved forecasting and intra-hour scheduling), changes in regional coordination (such as taking advantage of regional renewable resource diversity and trading energy imbalances among balancing authorities), and improvements in the use of DR resources that can help mitigate the need for ancillary services, or, in some cases, even provide ancillary services that require intra-hour or real-time dispatch capability. The size and character of that impact are difficult to characterize in a general way, as much of the impact will depend on the details of the mechanism and the resources that are close to participating or withdrawing from the participation in the market. If low-carbon resources are qualified to modify the net demand in a way that reduces the need for ancillary services, and if those low-carbon resources that are dispatchable are qualified to provide ancillary services, then the carbon emissions associated with ancillary services provision will be reduced.

5. Co-Benefits

The co-benefits that can be realized by increasing renewable generation (or reducing curtailment) are identified and explained in detail in Chapters 6, 16, and 17. Those benefits include potentially significant reductions in criteria and hazardous air pollutant emissions. VER integration strategies that enable and facilitate increased renewable generation will facilitate a greater level of those same co-benefits. In fact, in some cases the potential co-benefits of renewable generation simply can't (or won't) be realized unless appropriate integration strategies are in place.

Some air regulators will have heard claims that integrating large amounts of VER generation in coal-heavy regions can lead to increased emissions of criteria and hazardous air pollutants, because the pollution control equipment on coal-fired plants cannot operate efficiently if these plants are constantly varying their output in response to variations in VER output. Although this possibility cannot be dismissed entirely, this chapter has described a broad range of strategies for integrating VERs and it is wrong to assume that the only way to integrate VERs is by ramping coal-fired power plants up and down more frequently than already occurs.

Table 20-3 summarizes the most likely co-benefits associated with improved integration of VERs. Obviously some of these benefits do not derive directly from the integration mechanisms, but rather from the fact that they result in increased deployment and reduced curtailment of renewable generation. However, many of the integration strategies are useful for enhancing electric reliability and capturing other utility system benefits even if the emphasis is not on facilitating renewable generation.

Table 20-3

Types of Co-Benefits Potentially Associated With Improved Integration of Renewables Into the Grids

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	Yes
Employment Impacts	Yes
Economic Development	Yes
Other Economic Considerations	Yes
Societal Risk and Energy Security	Yes
Reduction of Effects of Termination of Service	No
Avoidance of Uncollectible Bills for Utilities	No
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	No
Avoided Distribution Capacity Costs	No
Avoided Line Losses	No
Avoided Reserves	Yes
Avoided Risk	Yes
Increased Reliability	Yes
Displacement of Renewable Resource Obligation	No
Reduced Credit and Collection Costs	No
Demand Response-Induced Price Effect	Maybe
Other	

6. Costs and Cost-Effectiveness

As a practical matter, when determining the costs, cost-effectiveness, and emissions savings associated with VERs, the costs of integration (including transmission needs) should be included. However, these costs are not unique to low-emissions resources. Integration costs are also an issue with more traditional forms of generation, which, because of size and inflexibility, may impose additional costs on the system. Most integration studies performed to date on renewable energy have focused on wind turbines, as wind has been the predominant variable-energy renewable technology to date. Many global studies suggest that the costs are between $1 and $7 per megawatt-hour for the relevant study ranges of 10- to 20-percent VER penetration.[28] Higher penetrations of variable renewables lead to higher costs, but experience is limited with high penetrations, and time and experience with integration techniques are likely to bring down the costs. State-specific and utility-specific studies in the United States show considerable variability in these integration costs, again based on the increasing wind penetration.

The role that integration measures and ancillary service mechanisms play in supporting the deployment of zero- and low-emissions resources is both design- and situation-dependent. Well-designed mechanisms can encourage improved operations, improved regional coordination, and the use of demand-side and other low-carbon resources to cost-effectively meet ancillary service needs.

Intra-Hour Scheduling

A technical report for the Western Electric Coordinating Council (WECC) compiled the results of three studies on the potential benefits associated with intra-hour scheduling, shown in Figure 20-5. These studies used dispatch models to compare the total costs of serving load in the Western Interconnection using hourly schedules versus the total costs using ten-minute schedules. The stated benefit of ten-minute scheduling is equal to the difference in these total costs. In addition to facilitating greater penetration of VERs, intra-hour scheduling alone could save consumers hundreds of millions of dollars per year.

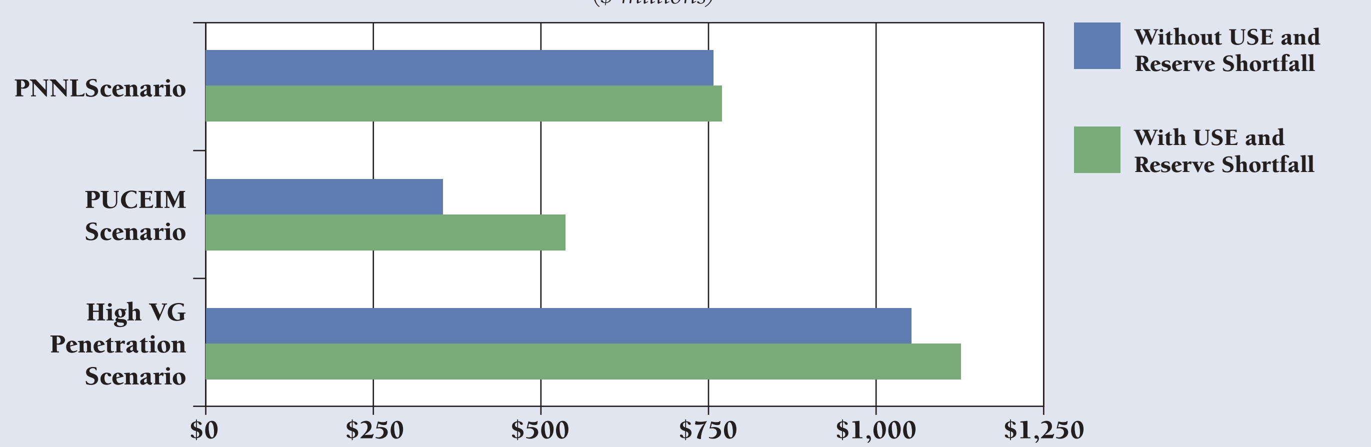
Dynamic Transfers

Dynamic transfers increase the supply of regional resources that can be delivered as a firm resource and thereby reduce cost, defer investment in new facilities, and increase access to high-quality renewable resources. Dynamic transfers can

Figure 20-5

Estimated Cost Savings for Intra-Hour Scheduling in the Western Interconnection[29]

($ millions)



28 International Energy Association. (2011). *Harnessing Variable Renewables: A Guide to the Balancing Challenge.* Available at: http://www.iea.org/publications/freepublications/publication/harnessing-variable-renewables.html

29 Hunsaker, M., Samaan, N., Milligan, M., Guo, T., Guangiuan, L., & Toolson, J. (2013). *Balancing Authority Cooperation Concepts to Reduce Variable Generation Integration Costs in the Western Interconnection: Intra-Hour Scheduling.* DOE Award DE-EE0001376. Available at: http://energyexemplar.com/wp-content/uploads/publications/Balancing%20Authority%20Cooperation%20Concepts%20-%20Intra-Hour%20Scheduling.pdf. The two bars in each scenario reflect cost estimates with and without an assumption that utilities would pay a penalty for unserved energy and failing to maintain adequate reserves.

directly reduce the cost of renewable energy procurement by making transfers of energy from BAAs where sun- and wind-resource quality is high to BAAs where renewable energy is in high demand. Dynamic transfer can also reduce the cost of integrating VERs in two ways. First, dynamic transfer increases the availability of regulation and flexibility resources that may be required at higher levels of VER penetration and thus keeps ancillary service costs down. Second, dynamic transfer ensures real-time firm delivery of the remote resources, and thus the integration services can be provided by the consuming BAA rather than the producing BAA.[30]

Energy Imbalance Markets

E3 estimated that the benefits of an EIM between CAISO and PacifiCorp could range from $21 million to $129 million for the year 2017, as depicted in Figure 20-6.

Improve Variable Generation Forecasting

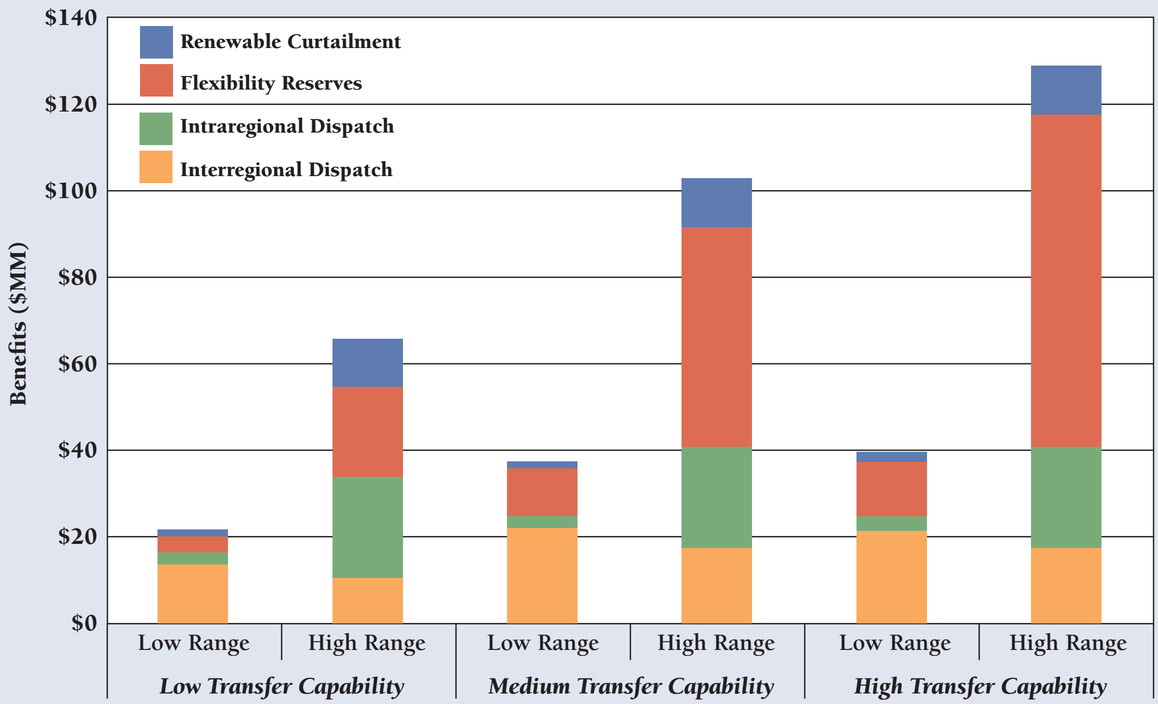
An NREL study of the WECC region found that improved day-ahead wind forecasts can significantly reduce operating costs and increase the reliability of large interconnected power systems.[32] Even a relatively modest ten-percent improvement in wind generation forecasts would reduce WECC operating costs by about $28 million per year when wind energy penetration is at 14 percent. For the entire US power system, the corresponding operating cost reduction would be about $140 million per year.

The impacts would be even greater at higher penetrations of wind energy. A ten-percent wind forecast improvement would reduce WECC operating costs by about $100 million per year with 24-percent wind energy penetration. For the entire US power system, the corresponding operating cost reduction would be about $500 million per year. These findings are summarized in Table 20-4.

Improved wind generation forecasts can reduce the amount of curtailment by up to six percent, thereby increasing the overall efficiency of the power system. Improved wind forecasts also increase the reliability of power systems by reducing operating reserve shortfalls. A 20-percent wind forecast improvement could decrease

Figure 20-6

Low- and High-Range Benefit Estimates Under Low (100 MW), Medium (400 MW), and High (800 MW) PacifiCorp-California ISO Transfer Capability Scenarios (2012$)[31]



30 Supra footnote 20.

31 Energy and Environmental Economics, Inc. (2013, March 13). *PacifiCorp-ISO Energy Imbalance Market Benefits.* Available at: http://www.caiso.com/Documents/PacifiCorp-ISOEnergyImbalanceMarketBenefits.pdf

32 Supra footnote 24.

Table 20-4

Annual Cost Reductions Attributable to Improved Day-Ahead Wind Generation Forecasts

Reduction in Forecast Error	Wind Energy Penetration	WECC Annual Operating Cost Savings ($M)	Estimated US Annual Operating Cost Savings ($M)
10%	14%	$28M	$140M
20%	14%	$52M	$260M
10%	24%	$100M	$500M
20%	24%	$195M	$975M

Source: Hogan, et al, at supra footnote 11.

reserve shortfalls by as much as two-thirds with 24-percent wind energy penetration.

Increase Visibility of Distributed Generation

In a study completed by KEMA for CAISO, the benefits of DER visibility were estimated through several 2020 simulations of production costs for different levels of DER penetration and to isolate the net benefits for each type of DER penetration. Costs of proposed communication architectures and monitoring devices were then compared to the benefits to determine:

- The greatest benefit of visibility would occur in the High DER Penetration Case, in which production costs of $391 million in 2020 could be saved through reduced load-following and regulation-reserve requirements. Of the DER profiles examined in the High Case, the greatest benefits would occur with photovoltaic system visibility ($176 million), followed by DR ($149 million), and then distributed storage ($63 million).
- For the Low DER Penetration Case, the benefits of improved visibility for all DER were projected to be $90 million. For the Medium DER Penetration Case, net benefits of improved visibility for all DER were projected to be $159 million.
- Costs of communications architectures to improve visibility were estimated at $37 million in capital costs and $1.3 million in operating expenditure in the High DER Penetration Case.[33]

Improve Reserves Management

The Western Wind and Solar Integration Study (Western Study) found that balancing authority cooperation can lead to operating cost savings because reserves can be pooled. To estimate the savings, the Western Study performed a sensitivity analysis modeling the Western Interconnection as five large regions instead of a system designed to approximate today's 37 BAAs. In the ten-percent renewable energy penetration scenario, the analysis found $1.7 billion (2009$) in operating cost savings region-wide as a result of larger balancing areas. Overall, the study found that significant savings can be gained from reserve sharing over larger regions with or without renewable resources on the system.[34]

Retool Demand Response to Meet Variable Supply

A widely respected study recently completed for the European grid provides further insight. Figure 20-7 shows the difference in system investment required between two scenarios with high penetrations of VERs – one in which demand is treated more or less as it is today, and the other in which DR programs are assumed to be able to move ten percent of the aggregate demand in the course of a day from periods when supply is less available to periods when it is more available. The result is less need for backup capacity, less need for curtailment of least-operating-cost resources like wind and solar, and less need for transmission, all leading to a net reduction in investment needs of more than 20 percent over the next 15 to 20 years.[35] If these types of

33 KEMA, Inc., National Renewable Energy Laboratory, and Energy Exemplar LLC. (2012). *Final Report for Assessment of Visibility and Control Options for Distributed Energy Resources.* For the California ISO. Available at: http://www.caiso.com/Documents/FinalReport-Assessment-Visibility-ControlOptions-DistributedEnergyResources.pdf

34 GE Energy for National Renewable Energy Laboratory. (2010, May). *Western Wind and Solar Integration Study.* Available at: http://www.nrel.gov/electricity/transmission/western_wind.html, cited in Porter, K., Mudd, C., Fink, S., Rogers, J., Bird, L., Schwartz, L., Hogan, M., Lamont, D., & Kirby, B. (2012). *Meeting Renewable Energy Targets in the West at Least Cost: The Integration Challenge.* Western Governors' Association. Available at: http://www.uwig.org/variable2012.pdf

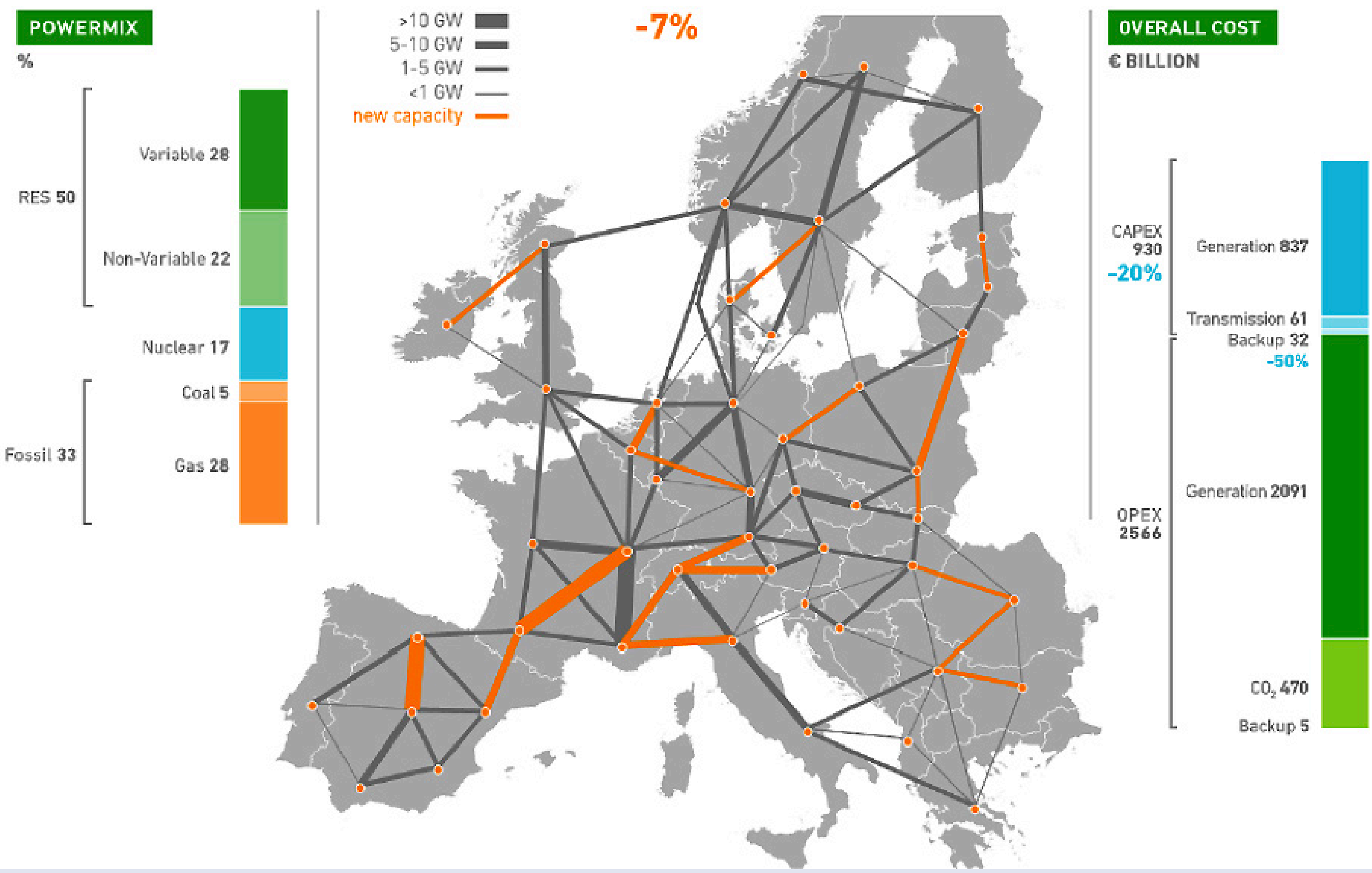
35 McKinsey & Co., KEMA, Imperial College London, and European Climate Foundation. (2011, October). *Power Perspective 2030: On the Road to a Decarbonized Power Sector.* Available at: http://www.roadmap2050.eu/project/power-perspective-2030

Figure 20-7

Effect of Demand Response on Future Investments in Resource and Transmission in the European Union[36]

2030 — Reducing the challenge: higher demand response

New grid capacity decreases by 7%. Overall investments decrease by 20%, with a 50% decrease in back-up capacity.



investment savings can be captured and passed through to retail customers, the benefits to consumers should be significant. The costs and cost-effectiveness of DR are addressed in greater detail in Chapter 23.

Utilize Flexibility of Existing Plants

It is difficult to estimate the potential cost, integration benefits, and implementation timetable for adding flexibility to existing plants. The costs are unique to individual plants, and modifications are a plant-by-plant decision. The authors of a report on the integration challenge produced for the Western Governors Association assumed the cost of minor retrofits from a regional perspective will be low if only a few plants undertake such retrofits and medium if more plants make minor retrofits. Integration benefits are projected to be low to medium, depending on the scope of the retrofits and how many generating plants undertake them. Confidence in both cost and integration benefit is low because of uncertainties about the scope and number of retrofits that may be undertaken. It is assumed minor retrofits could be implemented in a short to medium time frame.

Major retrofits are capital-intensive, so cost is rated medium to high. Authors also rated integration benefits medium to high, as more flexibility is presumed to be made available from major retrofits. But because retrofits are plant-specific and there is uncertainty about how many major retrofits may be performed, confidence in these

36 Supra footnote 35.

estimates is low. Implementation time is assumed to be medium to long.[37]

Encourage Flexibility in New Resources

The same report for the Western Governors Association on the integration challenge also looked at the potential for encouraging flexibility in new resources.[38] Although flexible capacity resources may cost more than other capacity resources, optimization of the electric power system as a whole should reduce costs in the long run. First, acquiring the best mix of resources, including those that complement wind and solar, will lead to more efficient system operation. Flexible, dispatchable resources that ramp up and down as needed to fill in around renewable energy production and meet net demand will allow increased utilization of low-cost energy.

Second, capacity resources that are designed from the outset to be flexible will provide these services at a lower cost than thermal plants that lose efficiency at lower utilization rates and have increased operating costs as a result of frequent starts and stops. When thermal plants are operated at partial loads during periods of high variable-generation output and low loads, fuel efficiency decreases and emissions increase, offsetting some of the benefits associated with renewable energy generation. Maximizing the benefits of renewable resources requires adaptation of thermal plants to meet new operating requirements.[39]

Power Perspectives 2030, a study of the feasibility of Europe's plan to reduce overall GHG emissions 80 percent by 2050, found that a more flexible portfolio of non-renewable supply resources is a key component of an economic long-term solution. Although some of this increased flexibility will come from an increase in the number of back-up generators with very low levels of use, the study found that more efficient options such as flexible gas-fired combined-cycle plants can continue to realize annual load factors comparable to what they see today – although with more erratic day-to-day operating profiles – and should therefore constitute the core of the non-renewable supply portfolio. Together with more responsive demand, expanded transmission systems and larger balancing areas, more flexible generating resources are needed to optimize production and consumption. Essentially, what is needed is a portfolio of "flexible base-load" supply resources capable of matching net demand without compromising efficiency.[40]

Energy storage devices can be extremely flexible but are currently more expensive in most applications than DR programs and other types of flexible resources. However, costs of storage technologies are declining and their potential is enormous. The emergence of energy storage resources is detailed in Chapter 26.

Improve Transmission for Renewables

The Western Wind and Solar Integration Study and the Eastern Wind Integration and Transmission Study both developed conceptual transmission overlays to test the viability of increasing the penetration of variable renewable generation in each interconnection. Although no optimization study was performed, both studies concluded that it may often be more economical to build transmission from sites with high-quality renewable resources (or to use existing lines more efficiently), than to site wind or solar installations in locations with lower-quality resources that are nearer to load. The cost of additional transmission is often a small fraction of the cost of additional generation equipment at the lower-quality site needed to provide equivalent amounts of electrical energy. Hence, the delivered cost of energy produced at the higher-quality site is lower than the energy cost from the lower-quality site, even though the former requires additional transmission.[41] This topic is covered in more detail in Chapter 18.

37 Porter, et al, at supra footnote 34.

38 Information in this section is from: Ibid.

39 MIT Energy Initiative. (2011, April 20). *Managing Large-Scale Penetration of Intermittent Renewables,* p 3. Available at: http://mitei.mit.edu/publications/reports-studies/managing-large-scale-penetration-intermittent-renewables

40 Supra footnote 35.

41 Milligan, M., Ela, E., Hein, J., Schneider, T., Brinkman, G., & Denholm, P. (2012). *Exploration of High-Penetration Renewable Electricity Futures.* Vol. 4 of Renewable Energy Futures Study. NREL/TP_6A20-52409-4. Golden, CO: National Renewable Energy Laboratory. Available at: http://www.nrel.gov/docs/fy12osti/52409-4.pdf

7. Other Considerations

The strategies that are available to integrate VERs are fairly universal, but the methods for procuring ancillary services, the costs of those services, and the allocation of costs to consumers could be quite different from one ISO to another and even more different when ISOs are compared to other balancing authorities. Some of these mechanisms, such as intra-hour scheduling, have already been fully implemented in many jurisdictions, whereas other mechanisms have yet to be fully tested anywhere.

8. For More Information

Interested readers may wish to consult the following reference documents for more information on integrating renewables into the grid.

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9. Summary

As regulators tackle the challenge of reducing GHG emissions, the need to ensure reliable electric service will remain. This chapter focuses on a suite of policies and mechanisms that can help to ensure continued electric system reliability as the electric system changes to include a higher penetration of VERs, particularly wind and solar EGUs.

Traditionally, system operators relied on controlling the output of power plants — dispatching them up and down — to follow fairly predictable changes in electric loads. First, based on load forecasts, generating plants were scheduled far in advance to operate at specified output levels. Then, in real time, these generators would automatically or manually adjust their output in response to a dispatch signal sent by the system operator as needed to balance supply with actual load. The need for ancillary services was usually modest. But today, as the penetration of VERs increases, the challenge of balancing electric system supply and demand is growing and changing. With an increasing share of supply from VERs, grid operators will no longer be able to control a significant portion of generation capacity. Therefore, grid operators will need new strategies for matching supply to a less predictable and much more variable net demand.

Although some new, flexible, fossil-fueled EGUs may be required to integrate renewables, many other strategies exist that can also ensure reliability in the presence of high penetration of VERs at least cost. The challenge for system operators (and air regulators) is to maximize the use of strategies that support GHG reductions. Broadly stated, these strategies involve DR programs that adjust demand to match supply (rather than the other way around), better use of existing system resources, and procurement of new resources that are more flexible.

The full potential of renewable resources to reduce GHG emissions simply cannot be captured unless these resources can be integrated cost-effectively and without impairing reliability. Fortunately, many of the integration strategies described in this chapter not only facilitate higher penetrations of renewables but also reduce system costs.