The Flexibility Workout

Managing Variable Resources and Assessing the Need for Power System Modification

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POWER SYSTEMS HAVE BEEN DESIGNED AND operated so that the demand for electricity can be met at all times and under a variety of conditions. Depending on the season, the climate, and the weather, demand can fluctuate significantly over a single day, week, or month. For example, in France the extensive use of electricity to generate heating creates a relationship between increase in electricity demand and decrease in temperature that amounts to close to 2,400 MW/°C. In addition to meeting the variability requirements, there is always some inherent uncertainty about future demand and the future availability of generators. The power system must thus be able to manage both variability and uncertainty.

Today, various combinations of hydro and thermal generation are used to manage variability; these operate as a portfolio to meet demand. Each generator possesses various characteristics, but the most important ones for the purposes of this article relate to flexibility.

Daily and weekly patterns of system demand help with prediction. Knowing the time horizon over which significant ramps take place (e.g., the morning rise) has allowed operators to plan and implement effective strategies for flexibility.

One characteristic that sources of variable renewable generation such as wind, tidal, wave, solar, and run-of-river hydro have in common is having an output governed by

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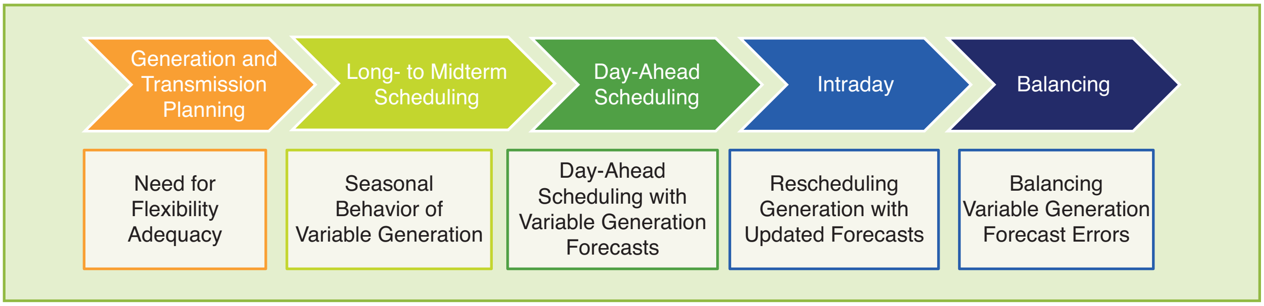

figure 1. The impacts of variable generation on the flexibility time line.

atmospheric conditions. Wind and solar generation may consequently be difficult to predict over some time scales. Large penetrations of variable generation (VG) lead to increases in the variability and uncertainty in the system's generation output, driving a need for greater flexibility. This flexibility will need to come either from flexible generation technologies or from alternative sources of flexibility such as flexible demand and storage. This article will discuss the additional flexibility needs introduced by variable generation from wind and solar power and will describe general approaches to analyzing the need for and provision of additional flexibility in the power system in both the operational and planning time frames.

The Challenge of Flexibility

The flexibility of the system represents its ability to accommodate the variability and uncertainty in the load-generation balance while maintaining satisfactory levels of performance for any time scale. There is no uniform definition of flexibility. In this article, we focus on the extent to which a power system can modify electricity production or consumption. We use ramp rate, minimum up/down time, and start-up time as indicators of flexibility, measured as megawatts available for ramping up and down over time.

At each stage of planning and operations, an understanding of variability is applied in different ways. Traditionally, long-term resource planning required little information about the variability of the net load in time scales of minutes to days, whereas characterizing the diurnal cycle is an important feature of day-ahead operational planning. The variability and uncertainty of VG production give rise to challenging ramping issues in the operational time frame; characterizing those issues in a planning context is becoming increasingly necessary. Operational flexibility is related to the system's ability to deal with variability within system operation time scales (normally from a day ahead down to real time). The type of operational flexibility required will depend on the time scale: increased frequency response and reserves for seconds to minutes, increased ramping capability for minutes to hours, and scheduling flexibility for hours to a day ahead. The time scales of flexibility, from the system-planning perspective down to very short-term operation, and the impacts of variable generation on flexibility can be seen in Figure 1.

The need for additional flexibility will depend on the increase in the demand for flexibility related to the penetration of variable renewables and also on the flexibility that already exists in the system. The assessment of overall system flexibility can be split into three stages:

1) It is first necessary to understand the flexibility requirements and assess the need (demand) for flexibility.
2) One must then evaluate the system's ability to supply flexibility by characterizing the flexible resources available to it and by looking at generation characteristics and existing alternative sources of flexibility, along with institutional constraints.
3) It is finally necessary to assess whether the available flexibility is sufficient to cover the need. If the system is not sufficiently flexible, additional options for flexibility should be considered based on relative economic merit. There is unlikely to be a one-size-fits-all solution; the value of the economic options will depend on existing options and their magnitude.

Figure 2 depicts how each part of the system affects the need for and supply of flexibility. The variability sources drive the need for flexibility to restore a system's energy balance, whereas the flexibility sources respond to restore that balance. In the middle, the system context oval contains facilitators that influence how much of the technically available flexibility may be deployed in real time.

Assessing the Need for Flexibility

There are numerous approaches under development to characterize the flexibility requirements of a system, and variability metrics with varying levels of complexity have been implemented. One conclusion is clear, however: a single number is not an adequate indicator of a system's flexibility requirements. The combination of regulatory preference for low-carbon resources and least-cost dispatch means that VG is normally dispatched first. As a result, the operation of the remainder of a system's resources is optimized to meet the demand net of VG ("net demand"). The variability and predictability of the net load set the requirement for system flexibility. Outages of generation resources also require a flexible response, but outages aren't considered here, since each system has an existing mechanism to deal with contingency events.

Examples of net demand for the German system are presented in Figure 3. It is possible to see that the shape of net demand is rather different from the shape of demand alone when significant solar is added to the system. In fact, power systems have different demand patterns and amounts of initial variability, so the net load variability will be different for different systems and VG mixes and penetration levels (see Figure 4).

It is relatively easy to characterize the ramping needs of a system if chronological load, wind power, and solar power data are available. The impact of VG depends on the relative magnitude of its variability when compared with the variability of demand. The time horizon is an important part of determining the flexibility requirements, since the size of net load ramps and the size of the flexible response are dependent on the time horizon. A wider set of resources is available as the time horizon increases, while at the same time the size of the net load ramps may also increase given a longer time horizon. Figure 5 shows the distribution of maximum upwards and downwards ramps at time horizons ranging from 5 min to 12 hours in a balancing area in the northwestern United States. It can be seen that for most time horizons, the maximum variability of net load is significantly less than the sum of the maximum variability of load and wind separately.

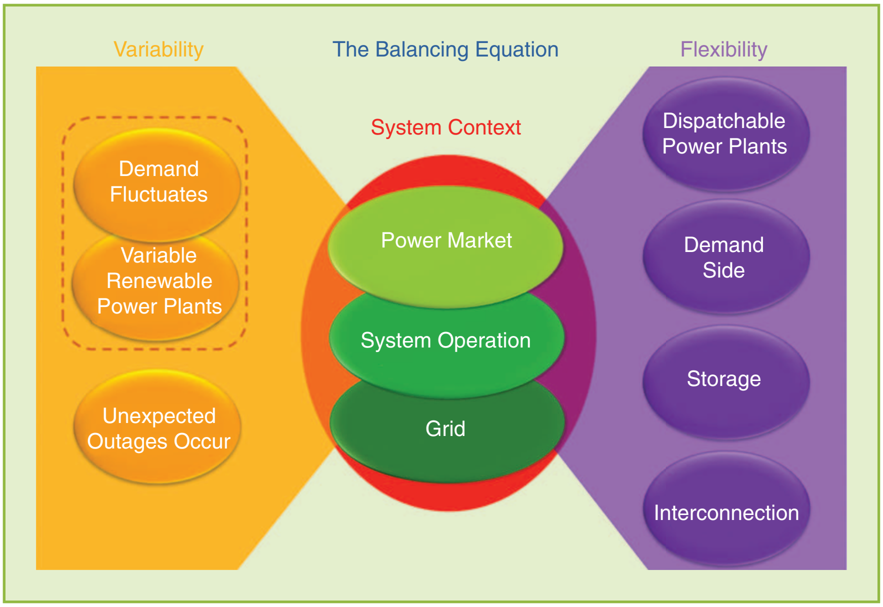

figure 2. Flexibility needs, sources, and enablers.

The most significant trend in net load ramp characterization is determining the largest ramp at each hour. This borrows from the capacity adequacy assessment logic that says if the largest peaks can be met, all the others can, too. Studies such as the Western Wind and Solar Integration Study have characterized these maximum ramps by time horizon, direction, and time of occurrence. Figure 6 shows the maximum upward one-hour net load ramps as a heat map for each month and hour. This intuitive visualization may be read an indication of the maximum flexibility the system should provide in order to meet its ramping requirements. This method shows which part of the variability in net load can be explained by diurnal and seasonal effects.

One important (though somewhat obvious) pair of insights is that when wind output is high, it is unlikely to increase significantly, and when output is low, it will not decrease significantly. These patterns, together with the fact that resources are backed off to accommodate wind output, mean that periods of high flexibility requirements often occur when there may be significant flexibility available.

Understanding the potential size and speed of the net load ramps as described above is important to ensure resources are available; knowing when these will happen is key so the resources can be deployed. Accurate net load forecasts, which can be calculated using both load and VG forecasts, enable system operators to ensure, with sufficient advance warning, that enough flexibility is available in each time period. Net load forecast errors do arise in practice, however, and are dependent on the ability to forecast both demand and VG for different lead times (see Figure 7). An assessment of the uncertainty of net demand for each lead time should also be factored into a system's requirement for flexibility.

Conventional Generation Flexibility: Can It Be Increased?

Conventional power plants are used today in power systems to supply almost all the flexibility needed. The flexibility

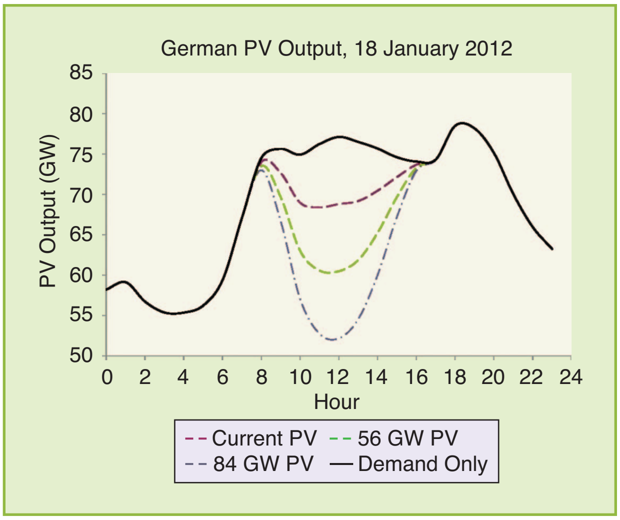

figure 3. The demand and net demand in Germany with various levels of installed PV capacity.

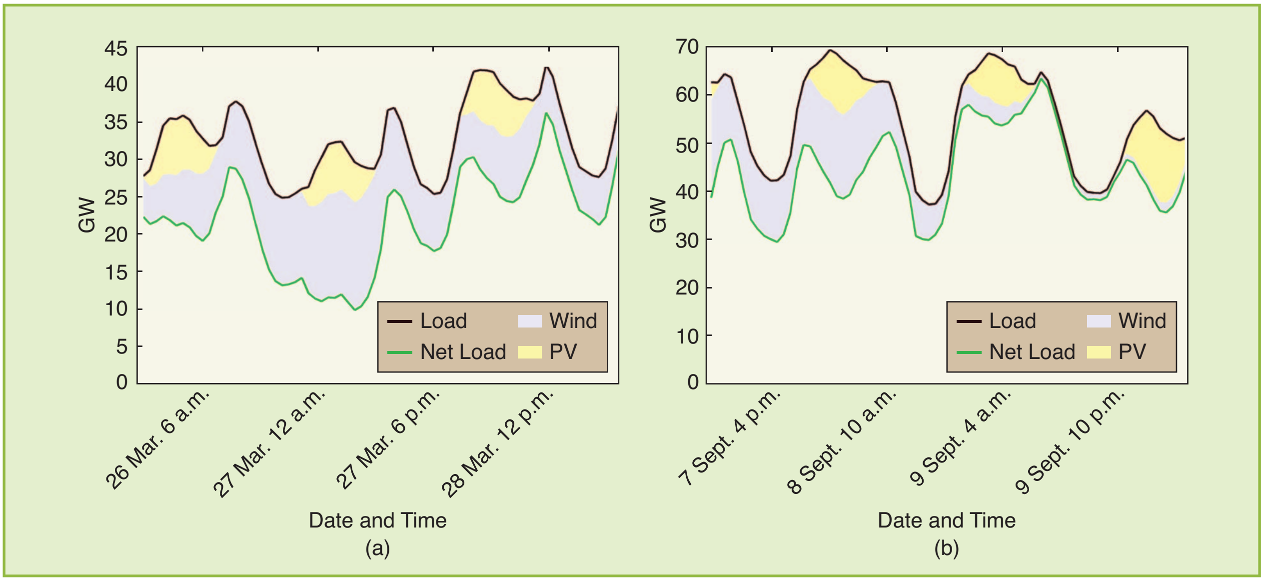

figure 4. A comparison of variability impact for different power systems for 25% VG in annual energy. (a) Iberian Peninsula (Spain and Portugal), with 25.6 GW of onshore wind and 12.1 GW of PV (2011 data) and (b) Germany, with 53.6 GW of onshore wind and 39.7 GW of PV.

attributes of a conventional generator may include its ramp rate, minimum stable output, and minimum start, stop, up, and down times. Traditionally, hydropower plants and gas-fired turbines have been considered more flexible than base load coal and nuclear plants. Most power systems also include some fast-starting units. There are large differences among coal- and gas-fired power plants, depending on whether they have been designed for base load operation or ramping and cycling. Run-of-river hydropower plants are usually quite inflexible, while reservoir hydro flexibility depends on the design, on the reservoir size, and on flow constraints.

It is possible to obtain more flexibility from existing power plants. Thermal plants can be refurbished so that they can be more flexible. In the province of Ontario, Canada, for example, coal plants have been retrofitted so they can ramp relatively quickly and achieve minimum stable run levels of about 10–20% of rated capacity. A more typical minimum run level for coal would range from about 40–70% of output, depending on design. In Denmark, in addition to lowering minimum load constraints, more flexibility was acquired from combined heat and power plants; during periods of low electricity prices, they could even switch to consuming electricity and providing heat through their heat storage. In France, nuclear power plants provide primary and secondary regulation along with some ramping capability. Increasing flexible operations from conventional plants will aid system flexibility requirements; in many cases, however, operating in a more flexible manner may have significant wear-and-tear

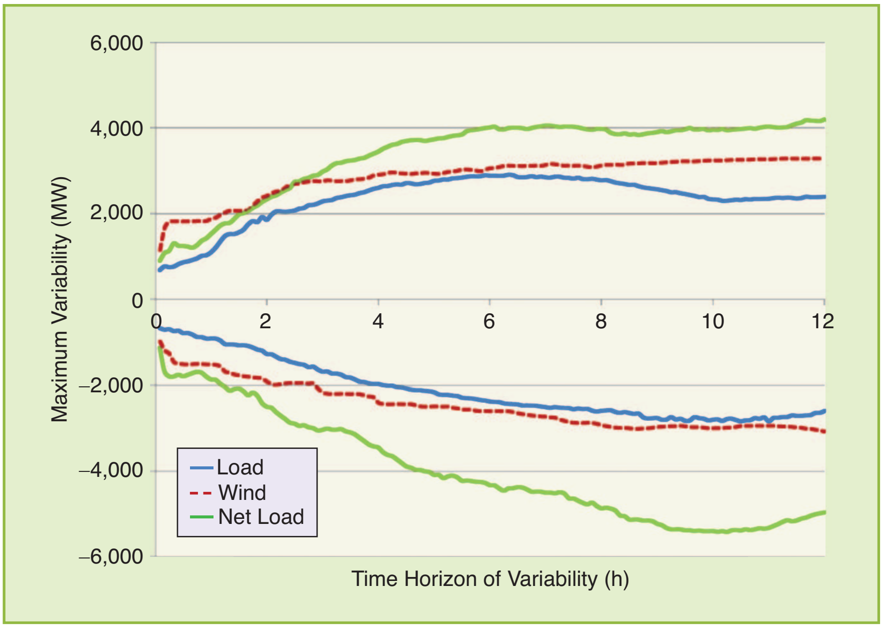

figure 5. Load, wind, and net load ramps in a northwestern U.S. balancing area in 2011, with peak demand of approximately 10 GW and 3.5 GW of installed wind providing 16% of energy over the year (courtesy EPRI).

implications for existing thermal and hydro plants.

There are relatively new technologies that offer significant flexibility. One example is related to recent advances in aeroderivative gas turbines. These units can be started and stopped many times with little resulting damage, have low minimum run levels and start/stop times, can ramp quickly, and have little if any heat rate penalties at low load levels. Another relatively new technology is the large reciprocating engine. Multiple small gas engines can be connected in parallel so that their combined output is scalable as desired. Plants can thus achieve full output within 5 min of starting. Efficiency at levels above 20 MW is similar to that of aeroderivative turbines (40 %) and is relatively flat all the way up to full output.

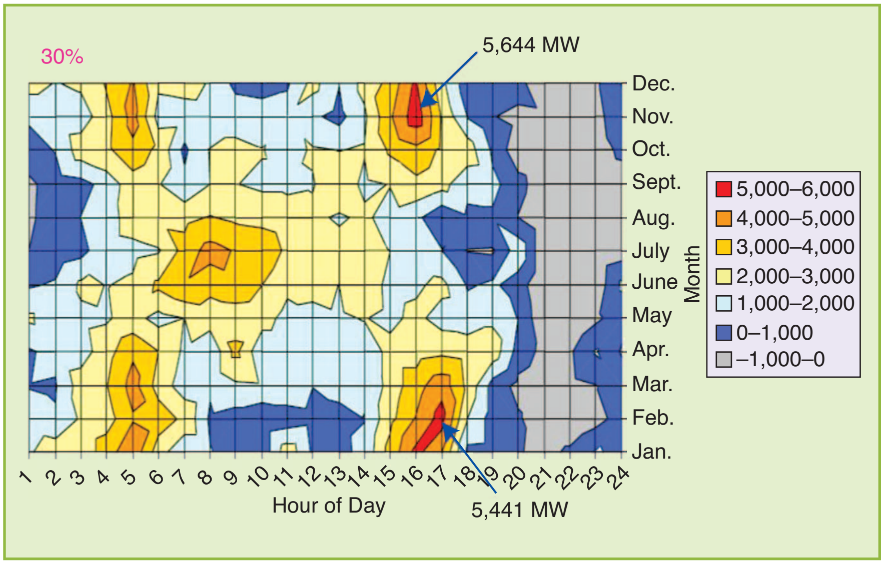

figure 6. One-hour maximum net load ramp for Western Interconnect study footprint (peak load of 160 GW), with a VG penetration level of 30% (source: WWSIS).

Demand-Side Flexibility: When Will It Be Used?

While flexibility resources are commonly found on the supply side, there is also the possibility of harvesting flexibility from demand-side resources (DSR). Large-scale industrial processes and direct control of certain loads have been utilized for many years. Recent advances in information and communication technologies (ICT), together with the large-scale rollout of smart meters, have created a new window of opportunity to make better use of DSR to increase flexibility.

The flexibility required can be obtained by scheduling and dispatching certain loads (either individually or as aggregations of smaller loads) according to system needs while respecting a set of predefined conditions, such as comfort levels. Alternatively, price-responsive demand can be utilized with price signals that reflect flexibility requirements. An example of the ability of such demand response to provide flexibility is found in France, where 6 million domestic water heaters, equivalent to 12 GW of potential demand, are centrally controlled to modify electricity demand. Demand flexibility from large consumers is also used in France to provide two-hour ramping reserve in critical periods. The ERCOT system has used its load-acting-as-a-resource (LAAR) product to provide half of its responsive reserves, mainly through large industrial loads. Figure 8 shows an example of an aggregate load profile increasing demand in the Pacific Northwest region of the United States, as part of a demonstration of the ability of warehouse refrigeration to provide system flexibility.

The potential of flexible demand has been recognized, but to date these services remain mostly underexploited. The key question is whether flexible demand can meet the needs for operational flexibility in an economically viable manner. Demand response will be best placed to provide flexibility in the period of several minutes to several hours. Uncertainty

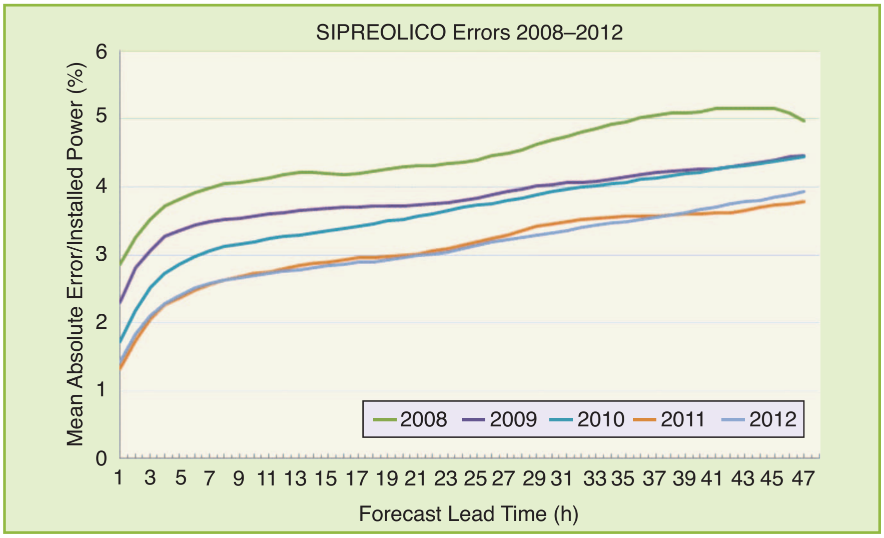

figure 7. Evolution of wind forecast errors with the forecast lead time in hours, from Spain (courtesy of REE).

about the availability of demand response, both in the long term (months to years into the future) and the short term (the next few hours to weeks), may limit its usefulness in replacing conventional resources to meet flexibility requirements.

Storage: Will It Be Cost-Effective?

In many ways, storage seems like an ideal flexible resource. It is quick to respond, can increase as well as decrease net demand, and in the case of battery storage can be deployed close to the load in a modular fashion. Providing power system flexibility with storage can generally be thought of as providing energy, power, or a combination of both. The provision of energy requires a continuous delivery of energy over a considerable length of time (typically hours). This could include provision of energy arbitrage, peak shifting, or storing of otherwise-curtailed wind; generally, pumped hydro storage or compressed air energy storage (CAES) are more suited to this application. Provision of power means rapid injection or storage of power over shorter time scales and is used to provide frequency regulation or ramping over shorter time intervals from seconds to minutes. Batteries and flywheels are well suited to this type of application.

Pumped hydro storage has been widely deployed worldwide for decades and has seen a recent increase in interest often linked to the increased need for flexibility. For example, the Portuguese power system uses pumped hydro to minimize the impact of forecast deviations, reducing wind curtailment and shifting energy from off-peak to peak times; plans are to expand it by a further 600 MW in the coming years.

Hydropower with reservoirs, which can be thought of as a form of storage, has been shown to be very well suited for providing flexibility, especially in areas where nonpower constraints do not dominate operation of the reservoirs. In the Nordic power system (Finland, Norway, and Sweden), there is a total amount of 47 GW of hydropower, with a reservoir capacity of around 120 TWh. Nordic hydropower has been extremely useful in providing flexibility for the integration of wind in Denmark. This hydropower flexibility has been sufficient for the needs of the Nordic system. Increased balancing needs outside the Nordic region and the EU market opening have led to interest in increasing the transmission capacity between the Nordic region and the European continent and United Kingdom. With an even higher balancing requirement, it would be possible to increase the flexibility of Norwegian reservoir hydro by adding pumping facilities to existing plants.

Significant round-trip efficiency losses coupled with the high capital costs of newer technologies make cost justification of new storage difficult. Additionally, most organized markets are not well suited to reward the specific attributes of storage assets. There is significant research being done to improve battery, CAES, and flywheel technologies to the point where they can be widely deployed as flexible resources. Battery storage has been deployed to date mainly in island systems. For example, on the Hawaiian island of Maui, a 21-MW wind farm is supported by an 11-MW battery storage system to ensure manageable ramps and to provide flexibility to the power system. The key question in the coming years is the cost-effectiveness of storage; this will require a greater understanding of flexibility requirements and the ability of storage to fulfill them. Studies to date have shown that justification of storage is difficult but that increasing penetrations of VG may provide enough value to build storage. For example, a study in Ireland showed that with the current level of wind penetration there (approximately 20% of annual energy demand), additional storage is not justified. For penetrations of approximately 50%, however, storage may be justified. An alternative application to provide frequency regulation is demonstrated by the installation by AES Energy Storage of a 32-MW battery at the Laurel Mountain wind site in West Virginia, on the PJM system. Different systems will see different levels at which storage costs are justified, and different amounts and types of storage will be possible in different systems, depending on the competing flexible resources (such as flexible demand) being deployed.

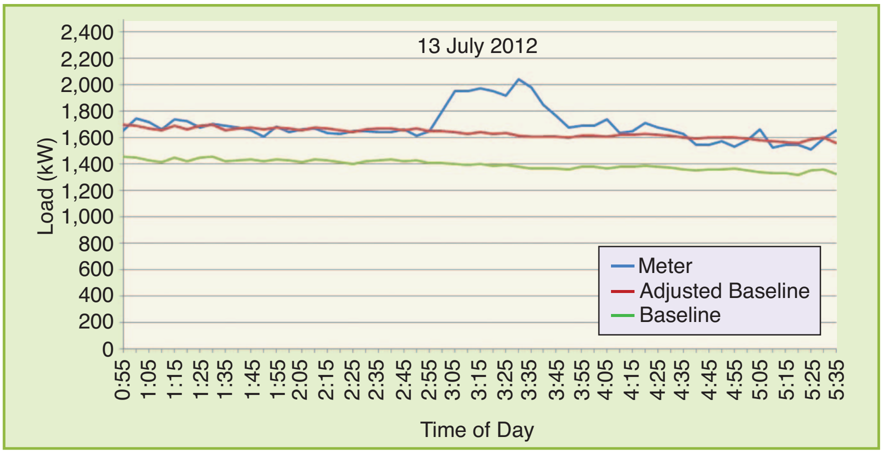

figure 8. Load profile of aggregated loads increasing demand to provide flexibility. Adjusted baseline shows expected output without activating flexibility from resources (source: Enernoc).

Wind and Solar Flexibility from VG

Wind and solar generation technologies have the technical capability for providing fast response to regulation signals. Down regulation can be provided when they are generating power. Up regulation can be provided by reducing the generation level and then providing more power when needed; forecast accuracy will have to be considered if wind is providing this service.

Wind and solar generation have close to zero short-run marginal costs, and any reduction in available production will be lost. As such, providing flexibility by reducing output will only be cost-effective under two circumstances. The first is when a small level of curtailment allows for the provision of system services from VG, which can in turn increase the ability of the system to economically absorb more VG. The second is if the value of the electricity that VG generates in a given location and time is zero or negative.

The first case is about the provision of system services as a by-product of power generation (that is, a power plant has to be generating to provide downward reserves). In order to guarantee system services, these units receive priority, leading to curtailment of VG. If VG itself can provide services, there is less need for curtailment. While the provision of system services may be associated with some degree of spilled VG energy (upward reserves), such measures are cost-effective when the value of the curtailed energy on the power market is lower than the value of the system service that can be provided due to curtailment. For VG, system services that do not require energy spillage (such as downward reserves) are more cost-effective in most circumstances. An example of wind power providing regulation can already be seen in the United States on the part of Xcel Energy and its subsidiary the Public Service Company of Colorado, where this method is used during light-load hours. Wind power plants can stay online, curtailing only part of their generation and thus providing sufficient up and down regulation to enable conventional power plants to operate at minimum load.

Even if all conventional generators could be turned down as VG sources provide system services, when VG output exceeds power demand (plus exports in case of transmission to neighboring areas), curtailing VG can still be cost-effective (unless demand can increase or storage is used). Also, if a certain amount of more rigid generation chooses to stay online to avoid a potentially costly shutdown and start-up, curtailing VG can be cost-effective in the short term from a system perspective. This would represent a paradoxical case in which VG provides flexibility for inflexible, dispatchable generation.

Support mechanisms, however, may mean that the provision of system services from VG is less attractive for VG plant owners. If feed-in tariffs or production tax credits predetermine the value of a kWh for the VG plant owner, this can lead to situations where it is economically attractive to run wind power generation at maximum even when the marginal value of electricity is negative. Consequently, VG may not have a financial incentive to provide system services even when it would be cost-effective for the system as a whole, unless the value of the system service being provided is greater than the price of energy plus the tariff or tax credit. As markets evolve to reward other forms of flexibility, including the ability to manage longer ramps, VG may also be able to provide these services; as in the case of existing system services, this will depend on the relative cost of doing so.

Institutional Flexibility and Market Design: The Enabler

There can be physical flexibility available in the power system that is locked due to institutional barriers or inadequate market design. Changing rules or market procedures can unlock existing flexibility and is often required to enable access to new types of flexibility, like that from the demand side, various storage resources, and flexibility from VG. Operational practices can also be flexible, for example, by enabling all potential flexibility sources to bid, using shorter time scales for bids, and enabling redeclarations at points closer to real time.

One example of markets' restricting the access to existing flexibility is given by regions that perform economic dispatch once an hour instead of every 5 or 15 min. In this case, all variability and uncertainty that occurs within the hour must be managed by the regulating reserve, the most expensive of the ancillary services. In much of the western part of the United States, for example, this is managed by units on automatic generation control (AGC) that ignore

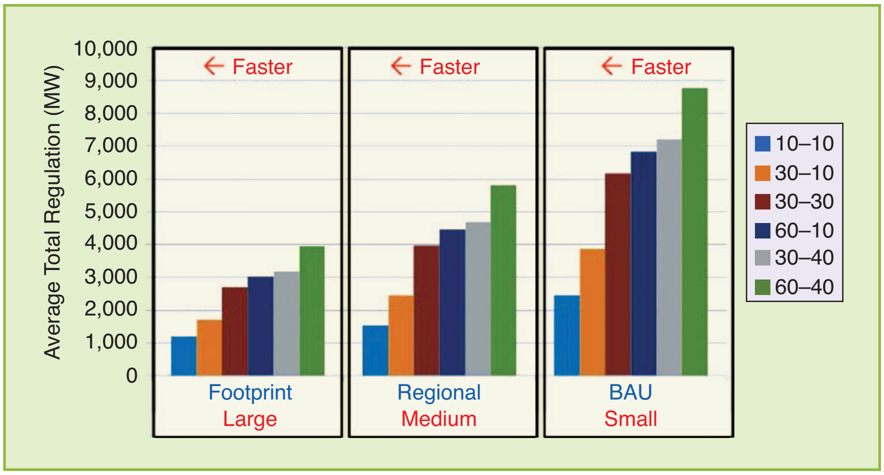

figure 9. The impact of balancing area size and dispatch intervals on operating reserve requirements for VG with a level of penetration of about 23%. The aggregate size of the system is about 160 GW, with 37 balancing areas aggregated at different levels to produce small, medium, and large balancing areas. Gate closure and response times are presented in the legend; for example, 30-10 means a 30-min dispatch interval and a 10-min forecast lead time.

table 1. Characterization of operational flexibility characteristics from flexibility sources (source: EDF).

				Flexibility Parameters	
Events	Services	Time Scales	Flexibility Sources	Down	Up
Capacity and reserve margins	Generation and flexibility adequacy	Years or months	Newly built plant Peaking plants Storage Flexible demand	Flexible plant with low minimum stable generation Storage charge Increase demand	Available generation Storage charge Loadshifting in peak days
Net demand daily variability and forecast errors	Day-ahead and intraday scheduling	Day-ahead until one hour before real time	Thermal plants Fast-start plants Hydro Nuclear Storage Flexible demand Thermal plants	Minimum up time Plant ramp-down rate Plant minimum stable generation Charge of storage Start flexible load	Minimum downtime Plant ramp-up rate Plant maximum generation Start-up time Discharge of storage Shift flexible load
Short-term net demand variability	Balancing and tertiary reserve	Less than one hour	Fast-start plants Hydro Nuclear Storage Flexible demand	Unit ramp-down rates Storage charge rates Start flexible load	Unit ramp-up rates Fast plant start time Storage discharge rates Shift/interrupt flexible load
Very short-term net demand variability	Primary response	Seconds	Plant primary response capability	—	Percent of maximum plant capacity available for primary response
	Secondary response	Seconds to minutes	Plant secondary response capability	—	Percent of maximum plant capacity available for secondary response

economic signals. Furthermore, even if a significant level of flexible generation exists, if it is not on AGC it won't be able to change its output until the next dispatch period. Moving to a shorter dispatch period results in a significant amount of generation that moves from uneconomic AGC to economic dispatch. Figure 9 shows the impact on regulation requirements in the western United States of alternative dispatch time steps and forecast lead times for different levels of aggregation. For 23% VG penetration, as shown in the graph, aggregating balancing areas and moving to a fast dispatch can achieve a nearly ninefold reduction in regulation.

The question of the market design needed to incentivize flexibility is an open issue, and much work is under way to help answer it. One approach is to allow scarcity pricing of energy, with no price caps. This results in significant price volatility; the objective is to use this volatility as a signal of the need for flexibility. An alternative approach is to design a new market for some type of flexible product, such as the flexible ramp product being pursued by the California Independent System Operator (CAISO).

Because there are several potential sources of flexibility, markets and institutional rules should focus on the performance characteristics that are desired and not on the technology that will provide it. This leaves the door open to technical innovation and the potential for new technologies to compete in their ability to offer flexibility services.

Assessing Available Flexibility

Assessing the availability of flexibility from various flexible resources is not as straightforward as assessing flexibility requirements. Resources may provide a flexible response from either an offline or online state, depending on start-up characteristics and the time horizon considered. The flexibility available from a given resource to meet a net load ramp is dependent on the current state of the resource. Operational constraints often limit the deployment of flexible resources; thermal limits on transmission, stability limits, environmental controls, and other factors may constrain the ability of a resource to provide its flexibility when required.

Adding to this complexity is the range of resources that can provide flexibility. Understanding conventional plant availability either a day ahead or years ahead may prove difficult, but this is further complicated when it comes to energy-limited resources such as energy storage, demand response, or hydroelectric power, some of which may also be limited by nonpower factors such as the availability of load to respond or the lack of hydropower flexibility due to environmental constraints on production. Obtaining flexibility from neighboring regions may be complicated by the fact that there are different market setups, limits on transmission availability, or coincident needs for flexibility in neighboring systems. A summary is presented in Table 1.

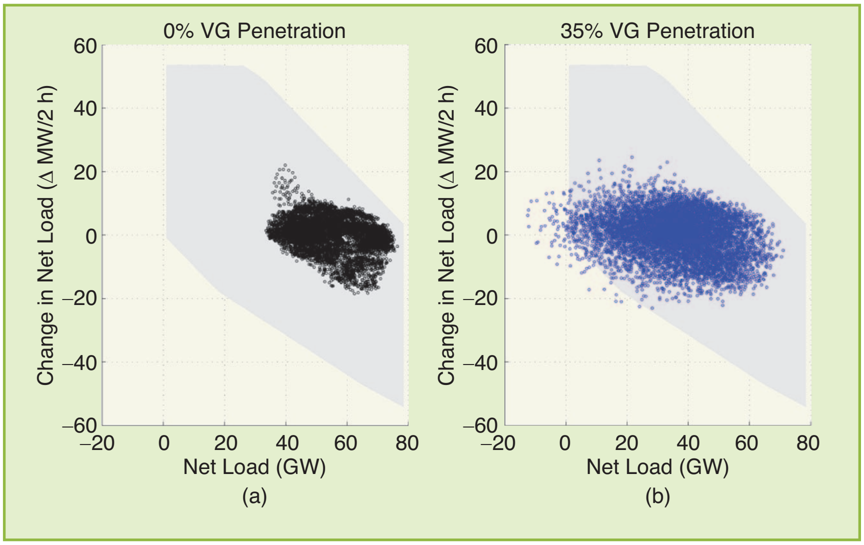

figure 10. Illustration of a comparison of maximum ramping capability of a test power system over a ramp horizon of two hours (gray area) with the need for flexibility for (a) 0% and (b) 35% VG.

In a planning context, understanding the available flexible resource expected at a given time requires suitable historical data, simulation, or estimation. In an operational situation, the flexibility available from resources can be continuously updated. There is a link between VG generation levels and available flexibility from the conventional power plants; at higher levels of VG, other power plants are dispatched at lower levels and can increase generation if VG generation drops.

One way of estimating flexibility from different sources is using hourly ramp rate and range. This method does not take into account flexibility available when offline, the range of time horizons, or the production state, but it does provide a straightforward means of ranking flexible resources. Another approach currently under development at the International Energy Agency (IEA) scores resources according to their ramping capabilities (e.g., 100 MW/15 min). This is then divided by any minimum generation requirement.

Assessing Flexibility Adequacy

After the flexibility requirements and the flexible resources available to manage them have been quantified, an assessment of the overall balance between the two can be made. How this balance is determined can depend on the application of flexibility metrics. Many metrics proposed to date have concentrated on the planning time horizon, where the range of possible outcomes is far greater, although operational flexibility requirements are beginning to be used in some areas. The IEA and the Electric Power Research Institute (EPRI), among others, have proposed high-level analyses in order to minimize the data and simulation burdens for planning studies. These methods use assumptions about resource availability to provide ramping capability to screen systems to determine if flexibility needs will be an issue. The main idea is to estimate the ramping capability of the power system for different ramp horizons. This is then compared with the flexibility requirement, derived from time series data of load and VG (see Figures 1 and 10). Using this high-level approach, it is possible to determine whether or not the system has a comfortable margin of flexible resources.

If deficits of flexible resource occur or only small margins between the resources and requirements exist, more detailed analysis can be carried out. Detailed simulation of future system behavior can be carried out in order to understand the interaction between flexibility requirements and the availability of resources. Tools that simulate unit commitment and economic dispatch at a high temporal resolution and consider the flows on the transmission system are needed to perform this more detailed assessment. The results of a more detailed study of this type are shown in Figure 11. Using three different probabilities of net load ramping expected in each hour, flexibility adequacy in the four-hour time horizon is shown to be the biggest risk in this system for both upward and downward ramps. It should be noted that over these long time horizons, the amount of additional flexibility that can be procured from altering institutional arrangements is likely greater than for shorter horizons.

Increasing the level of detail, an insufficient ramp resource expectation (IRRE) metric has been proposed to include probabilistic representations of net load ramps and the flexible resource available, based on full unit commitment and dispatch simulations. This IRRE metric mirrors the existing loss of load expectation (LOLE), equipping planners with a flexibility metric for each time horizon

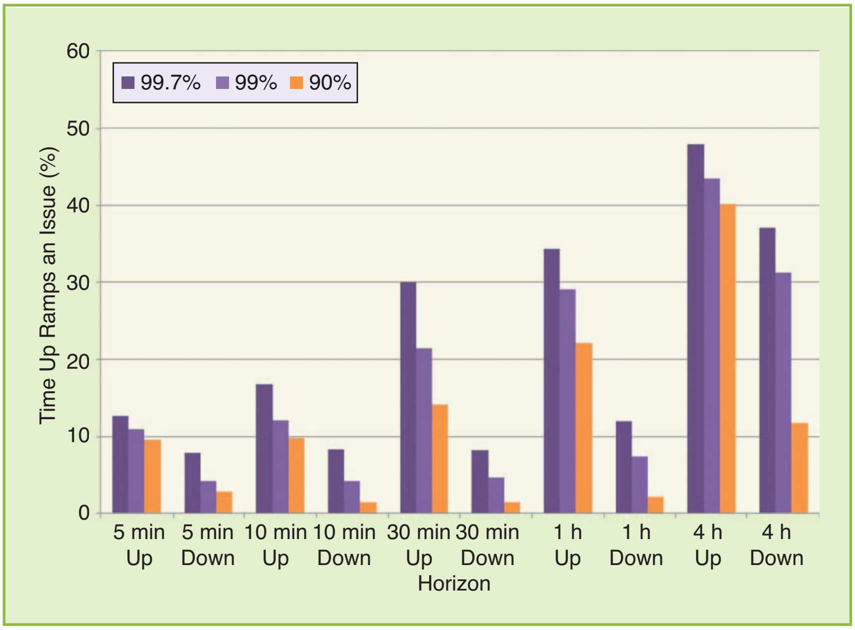

figure 11. Results from a detailed study on a test system at EPRI, showing how often the flexibility required is less than what is available for different time horizons and three different levels of confidence for up and down ramping.

that evaluates the aggregate risk posed to a system by ramping events. Development of algorithms to determine the capability of the transmission system to deploy flexible resources will add further detail to flexibility metrics and let transmission planners more thoroughly consider the need for flexibility.

The final arbiter of system flexibility to be considered is system operating and capital costs. Approaches have begun to be implemented in both academia and industry to determine when additional resources should be built and what characteristics those resources should have. By selecting the best option from a range of possibilities (one that takes into account the physical generation, transmission, and storage resources along with the institutional techniques, including altering markets and enabling demand-side flexibility, described above), the total costs of planning and operating a system can be minimized under a wide range of circumstances.

Summary

VG resources such as wind and solar plants will bring challenges that may require increasing the flexibility of power systems. Flexibility needs will be seen in the operational time scales, from minutes to a day ahead. Assessing these new flexibility needs, the resources available to meet them, and system flexibility adequacy will probably emerge as one significant aspect of power system planning. Metrics and methods are being developed to help in this task. There is no one-size-fits-all solution to increasing flexibility. Options that achieve the technical objective of fulfilling flexibility needs must be evaluated economically so that low-cost solutions can be identified. It makes little difference if new flexibility sources are found if the institutional and market means to access them do not exist.

Different flexibility technologies may compete with each other. Balancing net load variations and imbalances can be done using conventional power plants, storage facilities, DSR, or any combination of these. In addition, flexibility from neighboring areas can be accessed, which may require more transmission. For a realistic estimation of the most relevant technology, it is important that market prices—and the rules that set them—reflect the actual flexibility needs, as they act as signals for new investment in flexible resources.

For Further Reading

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