NERC

NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Essential Reliability Services Task Force

A Concept Paper on Essential Reliability Services that Characterizes Bulk Power System Reliability

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RELIABILITY | ACCOUNTABILITY

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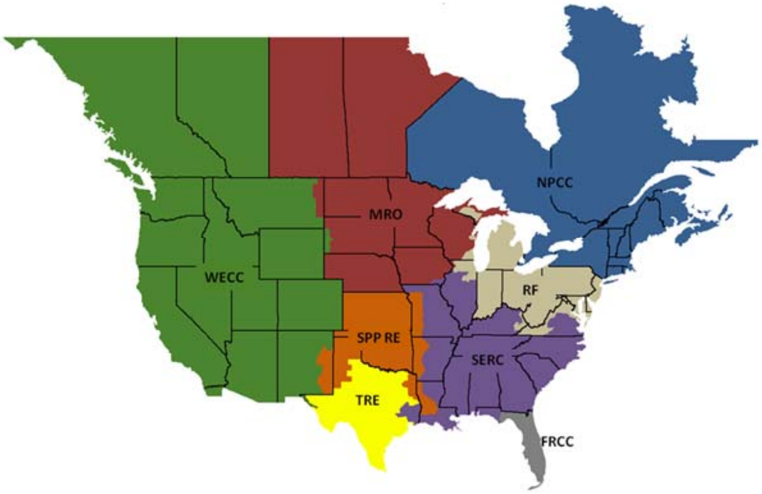
Preface

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to ensure the reliability of the bulk power system (BPS) in North America. NERC develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the BPS through system awareness; and educates, trains, and certifies industry personnel. NERC's area of responsibility spans the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization (ERO) for North America, subject to oversight by the Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada. NERC's jurisdiction includes users, owners, and operators of the BPS, which serves more than 334 million people.

The North American BPS is divided into several assessment areas within the eight Regional Entity (RE) boundaries, as shown in the map and corresponding table below.



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

Executive Summary

The North American BPS is experiencing a transformation that could result in significant changes to the way the power grid is planned and operated. These changes include retirements of baseload generating units; increases in natural gas generation; rapid expansion of wind, solar, and commercial solar photovoltaic (PV) integration; and more prominent use of Demand Response (DR) and distributed generation.

Conventional generation with large rotating mass (steam, hydro, and combustion turbine technologies) has provided necessary operating characteristics, defined here as Essential Reliability Services (ERSs), needed to reliably operate the North American electric grid. ERSs represent a necessary and critical part of the fundamental reliability functions that are vital to ensuring reliability, so these services must be identified, measured, and monitored so that operators and planners are aware of the changing characteristics of the grid and can continue its reliable operation. Some variable energy resources (VERs) and newer storage technologies may also have the capability to offer some components of these ERSs.

ERSs are an integral part of reliable operations to assure the protection of equipment, and are the elemental "reliability building blocks" provided by generation. In addition, DR, storage, and other elements are also necessary to maintain reliability. Gaps in ERSs can lead to adverse impacts on reliability. This paper identifies the reliability building blocks in two groups as listed below, and each group may have one or more characteristics. As the overall resource mix changes, all the aspects of the ERSs still need to be provided to support reliable operation. ERSs are technology neutral and must be available regardless of the resource mix composition.

Essential Reliability Services Building Blocks

- **Voltage Support:** Required to maintain system-level voltages on the BPS within established limits, under pre- and post-contingency situations, thus preventing voltage collapse or system instability.
- **Frequency Support:** Required to support stable frequency on the synchronized BPS and to maintain continuous load and resource balance by employing automatic response functions of a resource in response to deviations from normal operating frequency. The BPS must have the ability to raise or lower generation or load, automatically or manually, under normal and post-contingency conditions.

Historically, conventional generators with large rotating mass and the ability to respond automatically to frequency changes have provided most of the grid's ERSs. As non-conventional generators are introduced to the power system, it is becoming necessary to examine each of the ERS requirements to ensure that the BPS remains reliable. Until now, the grid has reliably operated without explicitly quantifying each ERS element, as most conventional resources provided these services just as a result of being part of the grid.

Recent trends and developments in industry are introducing alternative methods of achieving reliability through ERSs. Research has shown that VERs can be capable of providing some components of these ERSs; however, due to the variability of weather-dependent resources, the ERSs are not available continuously, which makes it difficult to rely on them consistently.

The changing dynamics of planning and operations warrants further study of these characteristics at both the micro and macro levels. NERC has commissioned the ERS Task Force (ERSTF) to study, identify, and analyze the planning and operational changes that may impact reliability as the resource mix continues to change. This report provides an initial overview of the primary elements comprising ERSs and describes anticipated conditions based on known forecasts of resource changes.

Introduction

Background

NERC's annual *Long-Term Reliability Assessment* (LTRA)[1] informs industry, policy makers, and regulators (and aids NERC in achieving its mission) to ensure the reliability of the North American BPS by assessing and identifying significant emerging trends in planning and operations that could negatively impact reliability. The 2013 assessment raised reliability concerns regarding the changing resource mix and included recommendations that NERC expand the methodology for assessing reliability. More specifically, the recommendations stated that NERC "develop a new approach and framework for the long-term assessment of ERSs to supplement existing resource adequacy assessments."[1] This report discusses the change in dynamics of the modern BPS; how new technologies are improving the existing ERSs, affecting them, or both; and what combination of approaches will be required to ensure BPS reliability in the future.

Considering impacts to ERSs as a result of significant changes in the operation of the BPS is not a new issue. In November 2000, the NERC Operating Committee charged the Interconnected Operations Services Subcommittee with the development of a reference document on Interconnected Operations Services (IOSs).[2] This was due, primarily, to the changes in the industry market structure that were taking place in many parts of North America at the time. The intent of the reference document was to:

- Define and describe the characteristics of IOSs.
- Describe the necessity of IOSs as "reliability building blocks" provided by generators (and sometimes loads) for the purpose of maintaining BPS reliability.
- Explain the relationship between operating authorities and IOS suppliers in the provision of IOSs.
- Provide sample standards that could be used to define the possible obligations of operating authorities and IOS suppliers in the provision of IOSs.
- Describe sample methods for performance measurement in the provision of IOSs.
- Describe sample methods for the certification of IOS resources.

While the drivers for the current effort may be different, the essential reliability building blocks remain the same. The IOS reference document provides a foundation for ERSTF effort. The IOS reference document says that IOSs must have the following provisions:

- **Regulation** is the provision of generation and load-response capability, including capacity, energy, and maneuverability that responds to automatic controls issued by the operating authority.
- **Load Following** is the provision of generation and load-response capability that is dispatched within a scheduling period by the operating authority, including capacity, energy, and maneuverability.
- **Contingency Reserve** is the provision of capacity deployed by the Operating Authority to reduce area control error (ACE) to meet the Disturbance Control Standard (DCS) and other NERC and Regional Reliability Council contingency requirements. Contingency reserves are composed of (1) spinning and non-spinning; and (2) supplemental reserves.
- **Reactive Power Supply from Generation Sources** is the provision of reactive capacity, reactive energy, and responsiveness from IOS resources, available to control voltages and support operation of the Bulk Electric System.

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[1] *2013 Long-Term Reliability Assessment*

[2] http://www.nerc.com/docs/pc/IOSrefdoc.pdf

- **Frequency Response** is the provision of capacity from IOS resources that deploys automatically to stabilize frequency following a significant and sustained frequency deviation on the interconnection.
- **System Blackstart Capability** is the provision of generating equipment that, following a system blackout, is able to: (1) start without an outside electrical supply; and (2) energize a defined portion of the transmission system. System blackstart capability serves to provide an initial start-up supply source for other system capacity as one part of a broader restoration process to re-energize the transmission system.

The ERS definition is fundamentally no different than the IOS definition. ERSs are part of Interconnected Operation Services and guide the ERSTF on how to address the changing resource mix. With the exception of blackstart capability, the ERSTF will address the same the “reliability building blocks” as defined in the IOS reference document. With the expected change in resource mix, impacts to blackstart capability may need to be addressed, but are not currently in scope for the ERSTF. A mapping of IOSs and ERSs is shown in Figure 1.

Essential Reliability Services	**Interconnected Operations Services**
Frequency Support	Frequency Response Regulation Load Following Contingency Reserve
Voltage Support	Reactive Power Supply from Generation Sources

Figure 1: Mapping of ERSs to IOSs

A recent joint NERC-CAISO study has pointed out that the significant resource mix changes have led to straining of certain generation and transmission system characteristics in California that are essential for maintaining the reliability of the BPS, and this issue may not be unique to California. Today, ERSs are largely provided by baseload and midrange conventional generating plants with significant rotating mass capability, with some VERs providing some ERS capabilities. The electric industry has established reliability expectations with these generating resources through knowledge accumulated over many years of experience. These conventional generation resources have predictable operating performance with well-understood reliability characteristics. New technologies and the adaptation of existing technologies can only occur if reliability performance requirements are addressed.

The convergence of large quantities of VERs (predominantly wind and PV), the increase in gas-fired generation, and the retirement of conventional coal and nuclear generation resources means a greater proportion of the total resource mix will have different ERS characteristics and will change operators’ control philosophy or requirements. ERSs available to operate the BPS change as VERs are added to the system, sometimes replacing the conventional electric generation provided by large rotating machines. Consequently, these services must be obtained from other sources besides conventional generation resources.

Figure 2 provides some context on the magnitude of the aforementioned resource mix changes over the next 10 years, where (a) shows wind and solar installations and (b) shows conventional generation retirements.

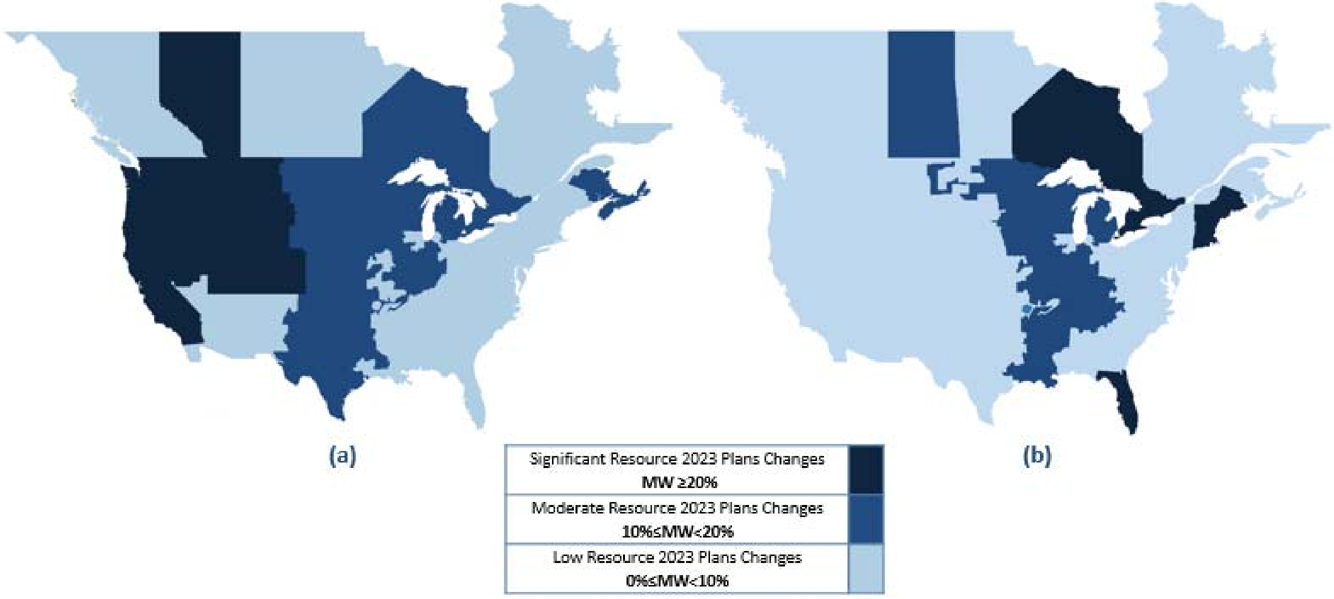

Figure 1: (a) Addition of Wind and Solar in 2023 and (b) Retirement of Conventional Generating Plants in 2023

Objectives

The objectives of this concept paper are to:

- Provide a reference for regulators and policy makers and to inform, educate, and build awareness on the ERS elements essential for the reliability of the BPS;
- Provide background information on the changes to the electric grids in North America and other countries that indicate the need to identify, measure and trend ERSs; and
- Identify, define, and formulate an initial standardized set of ERSs to be considered by the task force.

The task force recognizes that ERSs are technology neutral and must be provided regardless of the resource mix composition for a given operating area or Balancing Area (BA). ERSs must be assessed based on the functional needs of the BPS and require a defined approach for verifying that a certain level of performance can be achieved in the long term. Therefore, by specifying a technology-neutral assessment framework for ERSs, a larger pool of reliability resources could be considered as contributing to the overall system needs. This approach encourages the development and implementation of new technologies to further contribute to ERSs.

Essential Reliability Services

Reliability Building Blocks

The essential reliability building blocks that represent primary components of ERSs necessary to maintain BPS reliability[3] are provided by load, generation, DR (in some cases), and storage resources. As shown in Figure 3, these building blocks are Voltage Support and Frequency Support.

	ERSs in Functional Terms	Effects of Lack of ERS Availability
Voltage Support	• The primary objective of Voltage Support is to maintain the voltages in the transmission system within a secure, stable range. • Voltage Support is location-specific and requires reactive power control from reactive resources distributed throughout the power system.	• Localized voltage issues can spread to a wider area, causing loss of load. • Exceeding design voltage parameters can destroy equipment by breaking down insulation. • Undervoltage conditions can lead to motor stalls and equipment overheat. • Voltage collapse can lead to cascading drop in voltage and cause undesirable events.
Frequency Support	• Frequency Support ensures the frequency of the BPS can be synchronized and stabilized for both normal and contingency conditions. • Controlling frequency can be broken into four stages: 1. Inertial Response 2. Primary Frequency Response 3. Secondary Frequency Response 4. Tertiary Frequency Response • Daily operation of the BPS requires a continuous balance of load and resources (generation and demand-side resources). • Operational flexibility is needed to manage real-time changes in load and generation.	• Large frequency deviations can result in equipment damage and power system collapse. • Interconnection frequency deviation can result in: o Loss of generation o Load shedding o Interconnection islanding • Puts BPS stability and the reliability area at risk. • Imbalance in generation and load can overload transmission facilities. • Protection equipment can malfunction or be damaged. • Prolonged imbalance can result in violation of NERC Reliability Standard (BAL-001-1).

Figure 2: Reliability Building Blocks – Definition and Effects of Lack of Availability

ERSs are key services that are needed to plan and operate the BPS. Many of these services are widely provided under the current industry resource mix with mainly baseload conventional generating plants and load. This industry resource mix changes as the composition of VERs, DR, and storage devices interconnect to the BPS in larger amounts. The reliability building blocks are listed below with underlying ERS characteristics.

Voltage Support

- **Reactive Power/Power Factor Control** is the ability to control leading and lagging reactive power on the system to maintain appropriate voltage levels and acceptable voltage bandwidths, to maximize efficient transfer of real power to the load across the BES under normal and contingency conditions, and provide for operational flexibility under normal and abnormal conditions. Control of reactive resources can be performed by many reactive devices, such as SVCs, statcoms, capacitors, and reactors, in addition to conventional generating plants and adequately designed VER and storage plants.

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[3] Synchronous condensers, statcoms, and SVCs are also resources that provide ERS.

- **Voltage Control:** The ability of the system to maintain adequate levels of voltage in local and regional areas to support system loads and maintain transfers and devices connected to the system.
- **Voltage Disturbance Performance:** The ability of the system to maintain voltage support during and after a disturbance in order to avoid voltage collapse.

Frequency Management

- **Inertia:** The ability of a machine with rotating mass inertia to arrest frequency decline and stabilize the system.
- **Frequency Disturbance Performance:** The ability of a system to ride through disturbances and restore frequency levels to pre-disturbance levels.
- **Operating Reserves:** Operating Reserves (ORs) are characterized by the BPS's ability to maintain specified reserves (in some BAs), adequate reserves, or both, beyond the firm system demand. ORs consist of attributes such as regulation, load following, and contingency reserves (spinning, non-spinning and supplemental). Load following in a particular area is provided over a period of hours and a wider range of output as opposed to resources that provide regulation within a time frame of minutes and over a smaller output range. Resources that are slated to provide contingency reserve services are utilized during a contingency event, and contingency reserves ensure resources are available to replenish the amount of output used during the event, thus returning the system to the level of balance before the event.
- **Active Power Control (APC):** APC is the ability of a system to control real power in order to maintain load and generation balance. APC attributes can include:
  - **Frequency Control:** Frequency Control (FC) grants resources the ability to automatically intervene with real-power output as a response to frequency deviation on the system. This is achieved by a generating plant's autonomous governor response that adjusts its output to match interconnection scheduled frequency. FC usually refers to normal operating conditions (i.e., pre-contingency, stable system conditions). FC is mostly incentivized in all interconnections, except for the Eastern Interconnection, resulting in varied frequency control performance across all interconnections.
  - **Ramping Capability:** Ramping is using real-power control to raise or lower resources over a period of time to maintain load generation balance. Ramping capability is most needed at times of major load shifts, such as morning ramp-up, afternoon ramp-down, and evening ramp-up. In California, ramping needs have emerged as an ongoing issue with integration of large amounts of solar PV. As the typical load curve changes due to integration of off-peak electrical loads (e.g., electric vehicles and smart appliances), ramping needs may also change from morning and evening ramps to off-peak ramps.

Ancillary Services Compared to Essential Reliability Services

The required amounts of each ERS and the resources providing them will vary by BA, Region, and their associated BPS characteristics. Some ERSs are already well-defined ancillary services while others may become new ancillary services provided by market mechanisms of a BA or an RTO. Special case ancillary services could be addressed through alternative means, such as region or state-specific interconnection agreements.

Ancillary services, according to the *NERC Glossary of Terms*, are those services that are necessary to support the transmission of capacity and energy from resources to loads while maintaining reliable operation of the Transmission Service Provider's transmission system in accordance with good utility practice.[4] FERC defines ancillary services as:

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[4] Glossary of Terms Used in NERC Reliability Standards: http://www.nerc.com/files/glossary_of_terms.pdf

> "Those services necessary to support the transmission of electric power from seller to purchaser, given the obligations of control areas and transmitting utilities within those control areas, to maintain reliable operations of the interconnected transmission system. Ancillary services supplied with generation include load following, reactive power-voltage regulation, system protective services, loss compensation service, system control, load dispatch services, and energy imbalance services."[5]

Because of the critical role ancillary services play in maintaining reliability, they are considered a subset of ERSs. NERC recognizes ancillary services in organized and bilateral North American regions as the reliability attributes necessary to support a reliable BPS. Ancillary services were established as requirements of FERC's pro forma Open Access Transmission Tariff (OATT). Existing ancillary services were defined for a traditional system with conventional generating plants; however, with changing BPS characteristics, they could be addressed by means of a technology-neutral framework of performance metrics.

Frequency Management

Operating Reserves

Load and resource balance can be affected by a range of variations in system load and generation (e.g., evening load ramp or unintended loss of a generating plant). ORs ensure a sufficient amount of resources are available to address load and generation imbalance. Some types of ORs include regulation, load following, and contingency reserves. These categories can be distinguished into two modes of the system: pre-contingency and contingency. Regions differ in their OR definitions and requirements, but they all share some fundamental characteristics. Regulation ORs are an automatic mode of dispatch by plants equipped with Automatic Generation Control (AGC) to correct the current Area Control Error (ACE), while load following is a mode of dispatch to correct the anticipated ACE, both intra- and inter-hour dispatch. Contingency reserves include spinning reserves that assist in stabilizing the system immediately following a disturbance, and non-spinning reserves return the frequency to nominal and ACE to zero after the spinning reserves are utilized. Supplemental reserves are used to restore the spinning and non-spinning reserves expended after the disturbance once the system is restored to pre-contingency levels. Figure 4 represents that regulation and load following are services utilized during normal system operations, and contingency reserves are utilized after a contingency event.

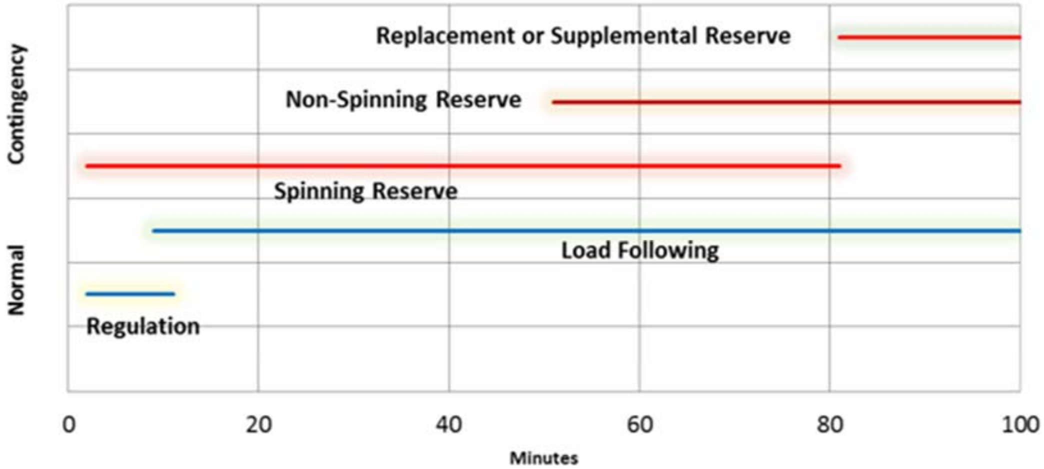

Figure 3: Operating Reserves for Normal and Contingency Conditions on a System

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[5] FERC Glossary of Terms: http://www.ferc.gov/market-ov ersight/guide/glossary.asp

Table 1 describes operating reserve categories generally known by the industry.

Table 1: Operating Reserves Categories	
	Description and Operation
Regulation	• Used to manage the minute-to-minute differences between load and resources and to correct for unintended fluctuations in generator output to comply with NERC's Real-Power Balancing Control Performance Standards (BAL-001-1, BAL-001-2)
Load Following	• Follow load and resource imbalance to track the intra- and inter-hour load fluctuations within a scheduled period
Spinning Reserve	• On-line resources, synchronized to the grid that can increase output in response to a generator or transmission outage and can reach full output within 10 minutes to comply with NERC's Real-Power Balancing Control Performance Standards (BAL-001-1, BAL-001-2) • Usually utilized after a contingency • Generally provides a faster and more reliable response • VERs may be non-spinning, but can be utilized as spinning reserves
Non-Spinning Reserve	• Similar in purpose to spinning reserve; however, these resources can be off-line and capable of reaching the necessary output within 15 minutes • Usually utilized after a contingency
Supplemental Reserve	• Resources used to restore spinning and non-spinning reserves to their pre-contingency status • Deployed following a contingency event • Response does not need to begin immediately

Reliability Considerations for Operating Reserve

Historically, demand changes over the course of a day have been predictable in terms of directional trends (i.e., consistent load duration profile). With the addition of variable generation, the net load (demand minus energy production from non-dispatchable resources) can shift the period of intra-day peak demand. For example, a large PV penetration can shift the daily load peak downward due to available sunlight during the day. However, large amounts of VERs that are aggregated in output, such as concentrated areas of wind production, can introduce greater variability within the course of an hour or several hours. Greater variability (and uncertainty) in these time frames requires dispatch in both directions, up and down, and makes optimization of the unit commitment more challenging. With the significant penetration of VERs in the BPS, services such as regulation and contingency reserves need to be analyzed within the context of these additions. As a result of the increased variability and uncertainty, OR requirements may change based on the available portfolio of resources in any given region.

Active Power Control

Traditionally, APC is defined as the ability of the system to control real power in order to maintain load and generation balance. While there are many combinations of ERSs that fall under APC, two additional ERSs may apply here, namely frequency control and ramping capability. Variable generation is typically managed to maximize the production of electric energy from a zero-cost source of fuel. Variable generation sources can be implemented with the capability of operating under economic dispatch and are increasingly doing so in some areas of North America. Production of real power from most VERs is predominantly a function of meteorology and is subject to the nuances of complicated atmospheric dynamics. Predictions of future output—minutes, hours, or days ahead—are also subject to these complications, and therefore can only be made with some degree of uncertainty. In BPS operations and control, accommodation must be made for the additional variability and uncertainty associated with these resources.

Frequency Control

Figure 5 illustrates the essential workings of frequency as it relates to the balance of load and generation, which are fundamental characteristics of a stable BPS. Stable system frequency is one of the primary measures of health for a large, interconnected electric power system. One of a System Operator's primary objectives is to maintain system frequency. In North America, operating frequency is 60 Hz.

Frequency

Frequency represents an indication of the real-time balance between supply and demand. Declining frequency indicates more demand than supply, while rising frequency indicates more supply than demand. Frequency balance must be maintained within tens of mHz of the target 60 Hz.

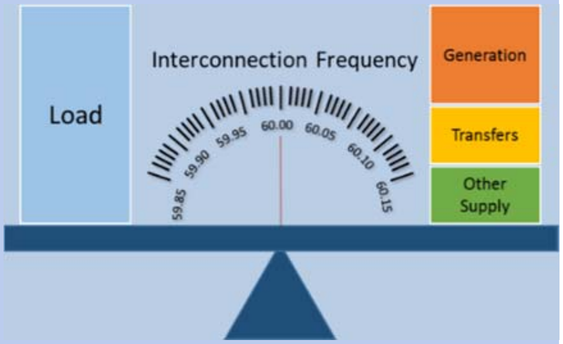

Figure 4: Frequency explained in terms of real-power control

Frequency control is required to maintain a stable system-level frequency. It has two stages of response on the system: primary and secondary frequency controls. Table 2 explains in detail the two stages of response.

Table 2: Frequency Control

ERS Element	Definition	Type of Service	Response Time
Primary FC	Automatic and autonomous response to frequency variations through a generator's droop parameter and governor response.	• Local frequency sensing • Provided through generator governor control • Can be provided through deliberate control of electronically coupled wind, solar, storage, and DR resources. • Less communication infrastructure • May include automatic load shedding.	t ~ seconds
Secondary FC	This is a service that returns frequency to nominal value and minimizes unscheduled transient power flows due to power imbalance between neighboring control areas.	• Centralized within control centers through AGC • Significant communication infrastructure • Typically provided by generation but some DR can provide this service.	Slower than Primary Primary < t > 15 minutes

Reliability Considerations for Frequency Control

Sudden disruptions to the supply and demand balance increase the potential for adverse BPS reliability impacts. Loss of one to several generating units or loss of significant transmission system elements can negatively impact system frequency, requiring recovery response to restore it.

There is also a concern that governor response may decline as the share of VERs in the system and retirement of baseload generation plants increases. It is common for conventional generators to not operate at their maximum rated output, allowing some governor modulation. This allows the generators to have some flexibility in the upward direction and help support the interconnection response to frequency deviations in a timely manner. VERs, on the other hand, are generally operating at full production and are only able to provide governor-like response in the downward direction. Overall, an operating area requires complete capability to manage frequency control for stable system operation.

Simulations of modern wind power plants have demonstrated improved frequency control by implementing fast response to an event at the cost of reducing a portion of its real-power production. Specific levels of frequency response reserves need to be modeled, analyzed, and incorporated in future planning and operating criteria. Specific levels of such support for varying resource mixes will need to be established based on the dynamics of their respective interconnected systems.

Ramping Capability

Ramping capability is the ability of a resource to ramp active power upward or downward in a certain amount of time. It is typically measured on a MW/min basis. The BPS is planned and operated to accommodate ramping requirements imposed by the daily load profile. System ramping capabilities are based not just on the type of fuel source available, but also the type of prime mover used in each generating unit (e.g., gas combustion turbine, steam turbine, etc.). The addition of variable generation, net-load variability, and uncertainty on the system require more flexibility in terms of providing ramping capability. Figure 6 shows forecast ramping requirements for 2020 load and net load scenarios conducted for CAISO.[6] Refer to the joint NERC and CAISO report for more information on the study assumptions used for this scenario.

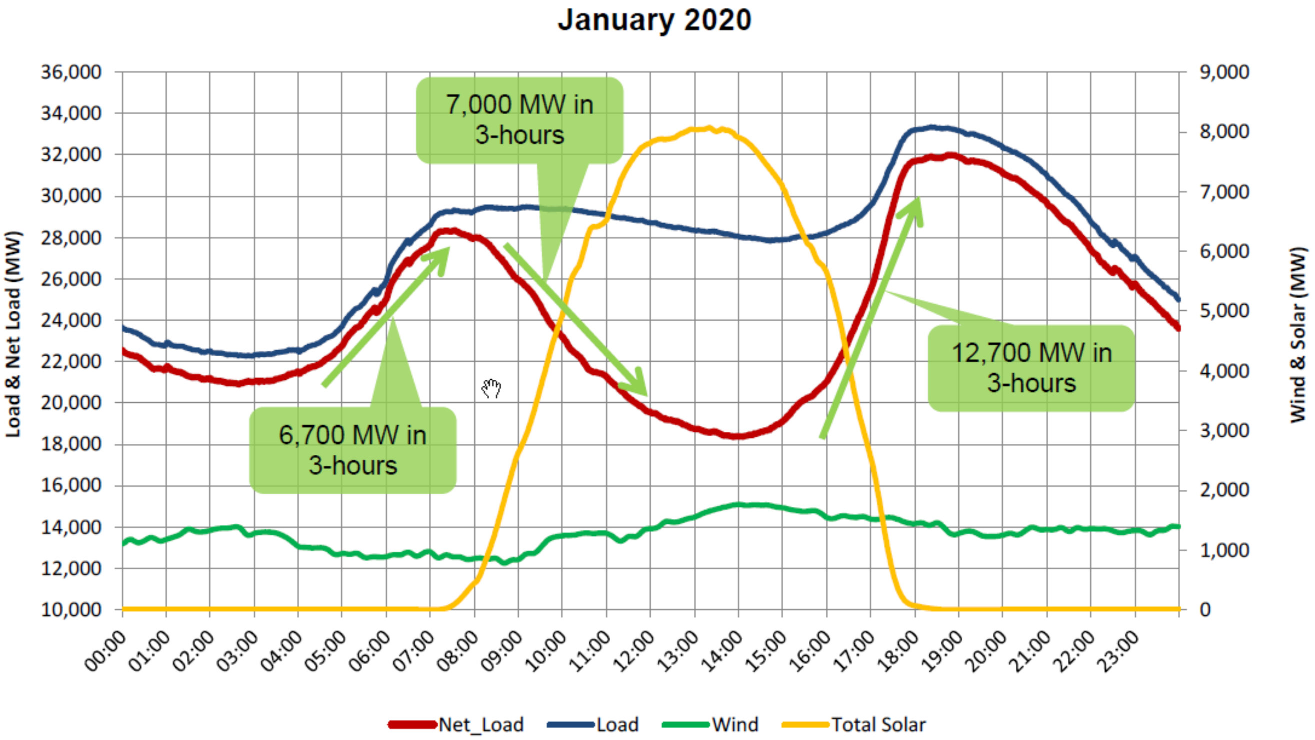

Figure 5: Wind and Solar Baseload Scenario for Ramping in 2020

Some modern utility-scale VERs have greater ramp control capability for control than coal-fired conventional generators (up or down). Downward ramps are accomplished by curtailing production,[7] which is a normal feature

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[6] A joint NERC and CAISO special reliability assessment report, 2013 *Maintaining Bulk Power System Reliability While Integrating Variable Energy Resources – CAISO Approach*, http://www.nerc.com/pa/RAPA/ra/Reliability%20Assessments%20DL/NERC-CAISO_VG_Assessment_Final.pdf.

[7] Modern utility-scale wind and solar plants can typically control their output from zero to whatever the full, currently available power level is. Conventional generators typically have minimum load levels that they cannot reduce power below. Minimum loads can be 40 percent or higher for coal plants, and nuclear plants may offer no control capability to power System Operators. Some combustion turbines must be block-loaded for emissions reasons and also offer no control capability. Ramping control is typically faster and more accurate for the new wind and solar plants than for fossil fired or nuclear plants.

for wind and utility-scale solar power plants; however, for Distributed Generation (DG) applications, these capabilities are not typical and there is limited control linked to System Operators. Consequently, determining the required levels of ramp control needed for a BA containing significant amounts of VERs is dependent on the level of resources, the resource mix, and the net load ramp behavior essential to BPS reliability. Figure 7 explains in detail ramping provisions provided by VERs.

Ramp rate, direction, and range are important because ramping capability requirements change hourly, based on both the system load (hour of day, day of week) and the availability of VERs (both wind and solar).

Consequently, system ramping capabilities and requirements are heavily intertwined with the dispatch control of the power system, which balances system needs with system economics.

Reliability Considerations for Ramping Capability

System Operators must accurately follow net load and minimize inadvertent energy flows. To meet this operational task, System Operators need enough flexible resources with sufficient ramping capability to balance the system in real time.

It is important to evaluate the overall composition of resources within a control area to ascertain both the capabilities and requirements for ramping and system balance. An aspect of this involves distinguishing between the ramping capabilities of conventional plants and VER resources and how they respond to an unexpected loss of generation. Further, it is key to determine whether or not these resources are connected to the distribution system. Large, utility-scale wind and solar plants are already required to have the capability to limit production and control ramp rates to support system BPS reliability. System Operators may have little to no visibility and control of distributed resources. A comprehensive study of ramping capabilities of generating plants currently interconnected to the BPS is needed to establish quantitative measures needed to support reliable balanced operation linked to the underlying resource mix. These measures may be used to establish an acceptable level of ramping needs for various regions depending on their resource mix, VER penetration, and guide requirements for new interconnecting VERs in regard to ERSs. The capability of the composite resource mix to either ramp up or down, disconnect from the BPS, or both is crucial in maintaining reliability as it also translates to disturbance performance.

Ramping Capabilities of VERs

There are four types of controlled changes in variable generation real-power production:

Ramp – The change in VER production over a defined period of time (e.g., MW/min.) The duration of the change may also be important and is sometimes used as a qualifier: “sustained” ramp. A ramp can either be natural (driven by meteorology) or controlled by operators.

Ramp Rate Limit – A change in VER production over time that is controlled by technology within the VER plant (e.g., coordinated pitching of individual wind turbine blades or a limitation imposed by the inverters in a PV plant on the change of production over time).

Economic Dispatch – The purposeful following of System Operator economic dispatch commands, within the current physical capability of the plant (Note: AGC is not the same as economic dispatch).

Curtailment – The purposeful limiting of real power production from a VER plant to an instructed level, which may be zero.

Figure 6: Ramping Capabilities pertaining to VERs

Inertia

Total interconnected inertia is an important reliability characteristic. Maintaining a sufficient level of inertial response is crucial to arresting the initial frequency decline and slows the frequency fall that occurs from the unexpected loss of a generation resource in the interconnection. The aggregate effect of inertia within an interconnection to arrest the initial frequency decline allows time for the generator governors and other responsive resources to restore the frequency to 60 Hz. Inertia is an inherent attribute of synchronous machines (generators and motors) and is not directly under a generator operator’s ability to control. Increased penetration of VERs, in addition to the retirement of conventional large coal-fired generation plants with massive prime movers, has increased the need to ensure that adequate sources of inertia are present within the interconnection and to maintain a sufficient level of inherent frequency support. Table 3 describes inertia in detail.

Table 3: Inertia

ERS Elements	Definitions	Type of Service	Response Time
Inertia	Stored rotating energy on the BPS. It is the accumulation of the inherent response of synchronous generators that arrests system frequency decline.	Provided inherently by synchronous machines • May be provided through deliberate control of VERs • Local frequency sensing – applicable to synthetic inertia only	cycles

New technologies offer new opportunities to provide ERSs. For example, wind power plants, some energy storage devices, and dc interties can be controlled to provide “synthetic” inertia. Synthetic inertia is a solution requiring wind generating units and energy storage plants with dc converters, which are normally insensitive to frequency changes, to be able to inject power into the BPS. This injection of power would be required following the loss of another generating unit, similar to conventional synchronous generating units, in order to arrest the initial decline in frequency. This function is achieved via sophisticated control actions. Some DR resources, if equipped with dc inverters, can also provide fast response that is required in the inertia and governor response time frames. All of these factors point to the need for an inertia ERS component with individual generating unit and BA-level system requirements. While the concept of inertia is not new, the concept of synthetic inertia is new and will need to be addressed in a coordinated fashion by the industry and device manufacturers.[8]

Frequency Disturbance Performance

Disturbance ride-through capability of an interconnected plant is an important generating unit requirement for normal and contingency conditions. A sudden disconnect, or a trip off-line, of a plant because of a disturbance on the system can cause power quality issues on the system and degrade BPS equipment. Frequency ride-through can be defined as the ability of a plant to stay operational during a disturbance and restore frequency to nominal after a disturbance. While it is accepted that the reliability of the grid depends on the adequacy of generation and transmission systems to meet load demand at all times, it is also heavily dependent on performance of the BPS system during and immediately after system disturbances. System disturbances are most often initiated from an unexpected transmission or generation event, but can also be initiated from distribution-level system events. During such disturbances, performance of all the remaining interconnected BPS system elements should enable the transition to an acceptable steady state. Generation resources and their associated control and protection systems play a key role in providing system dynamic performance.

Reliability Considerations for Inertia and Frequency Disturbance Performance

System reliability can be severely impacted during system disturbances if generation resources are inadvertently lost or their output significantly altered, causing voltage and frequency transients. Therefore, all generation resources not directly involved in the disturbance should continue to supply real and reactive power. All generators with available capacity at the time of the disturbance should respond to support BPS reliability.[9]

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[8] Grid Code Review Panel Paper, *Future Frequency Response Services*, https://www.nationalgrid.com/NR/rdonlyres/59119DD3-1A8D-4130-9FED-0A2E4B68C2D2/43089/pp_10_21FutureFrequencyResponseServices.pdf

[9] Nuclear plants may not be allowed to provide governor response by license.

Grid disturbance performance requirements are used to ensure that minimum capabilities of all resources to contribute to grid security following system disturbances are preserved. A requirement must clearly identify the grid conditions in which a generator must provide frequency disturbance performance as well as the specific parameters for meeting the performance requirements.

There are also concerns with fast reconnection after a fault, particularly for distributed resources. In general, wind and solar plants are often able to return to service faster than thermal plants because of their electronically coupled minimum available disturbance ride-through capability. Supply from these resources may be interrupted more often because of minimal ride-through capability, but the reason they can return more quickly is because they are not dependent on complicated thermal and mechanical systems, such as boilers. On the BPS, System Operators may elect to control these resources and use their quick-start functions to support reliability. However, distributed resources typically lack System Operator control and visibility, so they may reconnect and compromise the reliability of the BPS. Efforts are underway to require disturbance ride-through from distributed resources in the future through the IEEE Standard 1547 revision process. This effort supports future BPS reliability and will prevent further degradation of the overall resources with this capability.

Voltage Support

Reactive Power / Power Factor Control

Unlike APC and other ERSs, reactive power control is a supporting service for the real power that enables transmission of voltage through the BPS. The process of controlling reactive power on interconnected transmission systems is well understood from a system operations perspective. Similarly, maintaining an acceptable power factor is an understood planning and operational service, and it is, in some cases, enforced by BA and transmission operator (TOP) regulations. Figure 8 conceptually describes voltage and reactive power support, where different BPS elements could absorb and inject reactive power into the BPS to maintain acceptable system-level voltages.

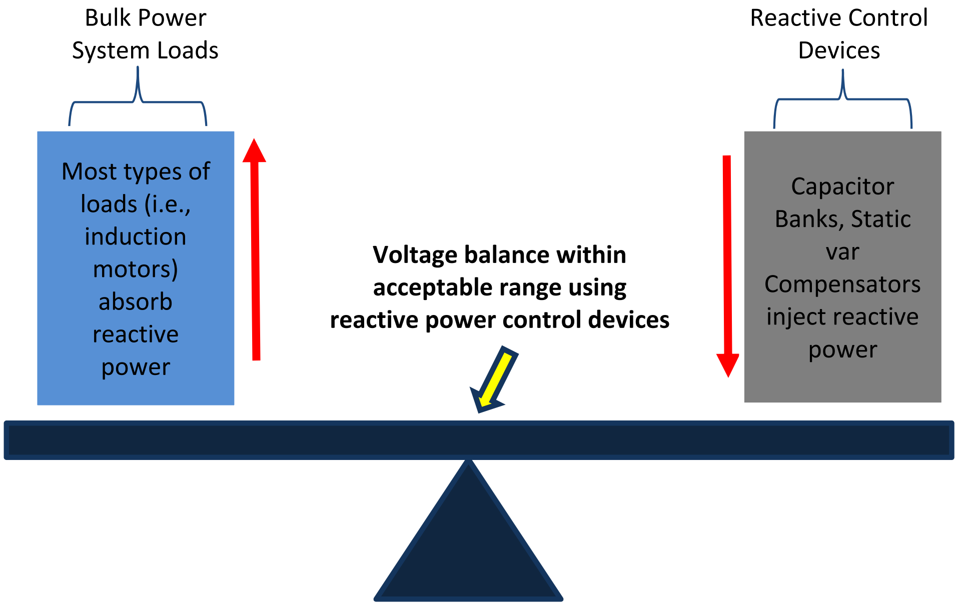

Figure 7: Graphical Representation of Reactive Power Control

Three objectives dominate reactive power management:

1. Provide reactive power source to loads, transmission lines, and transformers on the system.
2. Maintain unity power factor (provide exact amount of reactive power as consumed) at load aggregation spot, like a substation.
3. Minimize real power losses caused by overheating of equipment due to increased reactive power absorption.

While reactive support must be provided locally throughout the power system, these resources are controlled centrally because they require a comprehensive view of the power system to be accurate. Various devices, such as shunt capacitor banks, synchronous condensers, and static var compensators (SVCs), can provide reactive support. Generally, suppliers of the resources are not able to independently determine the system's reactive needs; only a planning and operating entity has sufficient information to know the system requirements, during both normal and contingency conditions, to deploy those resources effectively.

Voltage Control

Voltage control can be defined as the ability of a system to manage reactive power. Traditionally, in synchronous generators, the excitation system that provides direct current to the field winding of a machine maintains reactive power input and output to sustain a voltage schedule at the delivery point. However, the generating machine also provides reactive power through other parts, such as stator and rotor. Therefore, it must be noted that voltage control is dependent on both reactive power control and physically moving parts of a generating machine. Capacitors, reactors, SVCs, and similar devices also provide reactive power and voltage control. Generators and various types of transmission equipment are used to maintain voltages throughout the transmission system. In general, injecting reactive power into the system raises voltages, and absorbing reactive power lowers voltages. Voltage control requirements can differ substantially from location to location and can change rapidly. At low levels of system load, voltages may increase due to injection of reactive power on the BPS. Conversely, at high levels of system load, voltages may decrease due to absorption of reactive power on the BPS.

Voltage Disturbance Performance

An inherent characteristic of the BPS is that it must have acceptable levels of voltage during normal operations and after a disturbance. These phenomena could be termed as voltage stability or voltage profile control. Unavailability of sufficient reactive power can lead to voltage instability and ultimately can cause partial or complete voltage collapse. The BPS is designed and built to withstand disturbances up to certain levels of instability in voltage. The industry needs to continue to review and analyze voltage performance under normal and post-disturbance conditions.

Reliability Considerations for Reactive Power/Power Factor Control, Voltage Control, and Voltage Disturbance Performance

Reactive power requirements can change rapidly, especially under contingency conditions. Resources with dynamic reactive power control capability (all generators, SVCs, and synchronous condensers) are necessary to maintain system reliability. System Operators must monitor and manage reactive power reserves just as they must monitor and manage real power reserves. Changes in the resource mix of the generation fleet will impact reactive power management and controlling voltage. Reactive power cannot be transmitted as far as real power, so generator reactive capability and location are particularly important in managing voltage.

Synchronous generators are excellent resources for reactive support and Voltage Control. Power system reactive power and Voltage Control requirements must be considered when the generators are designed and built, with additional costs incurred to obtain the needed capabilities. Utility-grade inverters that couple modern wind generators and PV plants with the BPS can incorporate dynamic reactive power and voltage control capabilities as well.[10] Obtaining greater capability comes with greater cost, as is the case with conventional generators.

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[10] Inverters can be designed to provide dynamic reactive support to the BPS even when wind or solar generator is not producing real power, a capability that very few large synchronous generators can match. The added cost must be considered when deciding on this capability.

Resource Mix Impacts to ERSs

There is an inherent need for changes to the existing planning and operations model due to the convergence of various changes to the North American BPS. These changes include retirements of baseload generating units; the addition of natural-gas-powered plants; increasing levels of wind, solar, and commercial PV integration; and prominent use of DR. These changes alter the resource mix, and focus the need on determining the required elements of ERSs needed to support a reliable BPS. Power system planners must consider the impacts of all these changes in power system planning and design, and develop the practices and methods necessary to maintain long-term BPS reliability. Operators will require new tools and practices, which may include potential enhancements to NERC Reliability Standards or guidelines to maintain BPS reliability.

Figure 9 shows the planned gas-fired generation and renewable resources as well as conventional plant retirements expected in the near future. In relation to ERSs, as the resource mix changes, the requirements for maintaining ERSs may change. For example, as solar penetration continues to increase in California, the morning up-ramp and evening down-ramp profiles will change based on reliability requirements.

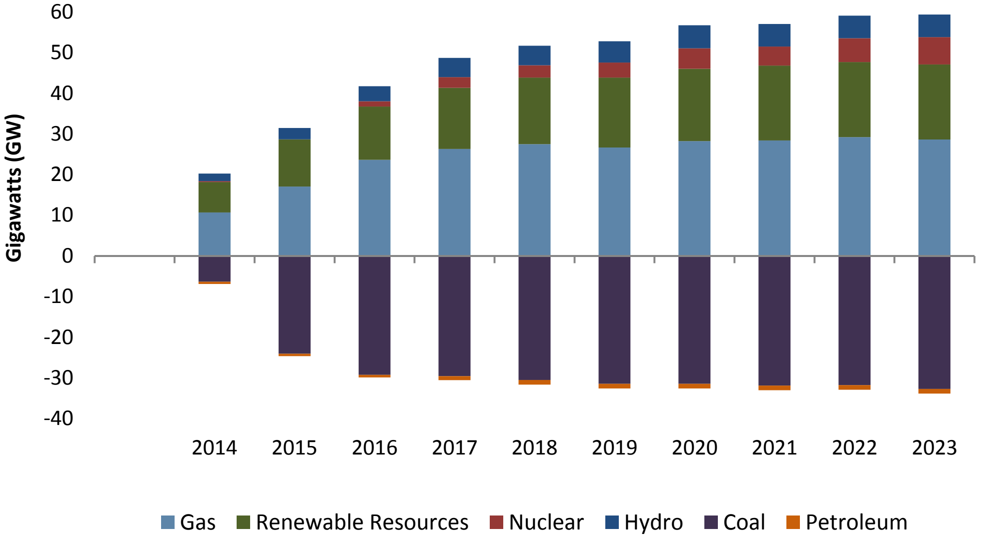

Figure 9: LTRA Projected change in resource mix and baseload retirements

Gaps in ERSs can lead to adverse impacts on reliability. As previously described, resource adequacy addresses the question of whether a given system has enough resources to meet expected demand. However, being resource adequate does not necessarily equate to having the right type of resources with the right functional capabilities to maintain reliability. For example, a system with all coal-fired generation may not have the ramping capability to support hourly changes in load. On the other hand, a system that has significant penetration of wind and solar may not be able to provide the right level of operating reserves or frequency response needed to support other contingencies on the system. In Figure 10, a graphical display of the resource stack is presented along with the ERS "building blocks." The "Potential Future" resource stack represents a system with high levels of variable generation and less conventional generation. While both hypothetical systems may be above the reserve margin target, several gaps (represented by white blocks) are present. It is important to note that with supporting policies, incentives, and standards, gaps in ERSs can be severely diminished. ERSs are technology neutral and must be provided regardless of the resource mix composition.

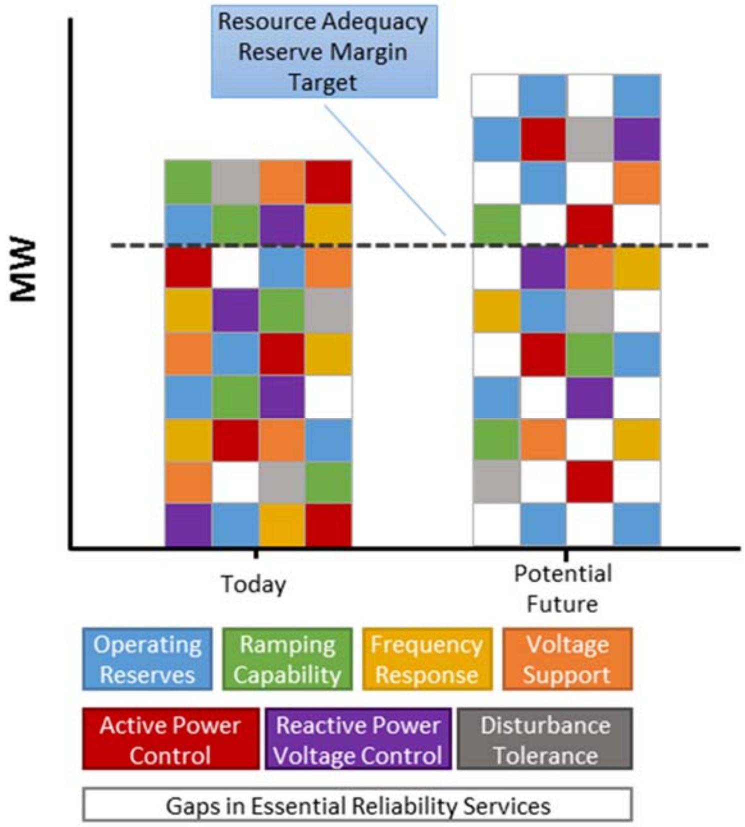

Figure 10: Potential Future Gaps in ERSs

Emerging Resources – Distributed Energy Resources

An important element of BPS reliability is the ability to support grid reliability during a disturbance, which requires both voltage ride-through (VRT) and frequency ride-through (FRT) capability. For large amounts of behind-the-meter distributed energy resource (DER) integration, a transmission contingency can result in voltage or frequency deviation and trip the DER resource, compromising BPS reliability. Because frequency is a wide-area phenomenon, resources with little tolerance for frequency deviations (e.g., current solar PV units connected at the distribution level) can significantly impact BPS reliability, particularly when they share the same trip points.

As an example, Germany has an installed capacity of over 10,000 MW of distributed PV and has recognized the need to integrate DERs into the dynamic support of the network. It has proposed the following:

1. Prevent DERs from disconnecting from the system due to faults on the system;
2. Require DERs to support the network voltage during faults by providing reactive power for the system; and
3. Require DERs to consume the same or less reactive power both prior to and after the fault clearance.

Distributing generation resources throughout the power system can also have a beneficial effect if the generation has the ability to supply reactive power and this ability is coordinated by System Operators. Without this ability to control reactive power output, performance of the transmission and distribution system can be degraded.

Given the growing penetration of distribution-connected variable generation, there is an increasing need to understand its characteristics and overall contribution to ERSs. NERC assessments have concluded that DERs, in aggregate, can impact the operation of the BPS.

Emerging Resources – Demand Response

Demand Response (DR) is a growing component of the BPS resource mix. Industrial, commercial, and residential DR has been effectively used for decades for peak reduction. NERC long-term reliability assessments have noted the benefits that DR provides, along with careful considerations of issues needing to be studied with the increasing portfolio of DR.

Advances in communication and control technologies are responsible for expanding the ability of all types of consumers to respond directly and quickly to frequency deviations, including disconnecting their behind-the-meter resources and responding to System Operator instructions. DR is not a single piece of technology; rather, it is any piece of technology that controls the rate of electricity consumption rather than the rate of generation. DR, with suitable added technology components, can also provide regulation, governor response, spinning reserve, non-spinning reserve, and supplemental operating reserve[11], for example, the Electric Reliability Council of Texas (ERCOT) obtains half of its spinning reserves from DR and is considering a DR-based Fast Frequency Response Service (FFRS) that is positioned between inertia and governor response.

DR can enhance power system reliability by increasing the reserve resource pool available to the System Operator, provided that there is adequate control, visibility, and availability. This is especially important as conventional generators retire and as VERs increase reserve requirements. DR technologies that can meet prevailing performance criteria should be considered as part of the fleet of resources available for all power system balancing needs. Different technologies can be successful for different applications in different locations, depending on the specific characteristics of the local loads.

Significant levels of DR have enabled peak load shaving and reliable operation of the BPS; thus this emerging trend is an important future service to be monitored by NERC's long-term and seasonal assessments.

Emerging Trends and ERS Observations

A changing generation mix has the potential to impact the reliability of the BPS, especially in areas with high percentage changes. The following sections provide several regional examples.

California

The NERC-CAISO 2013 special assessment provides insight into CAISO's approach on renewables integration. Figure 11 depicts current and projected variable generation penetration in California. The report concludes that improved operating practices, procedures, and tools are critical for accommodating large amounts of VERs (i.e., 20–30 percent) into any power system and for improving the control performance and reliability characteristics of the power system as a whole. System resources supporting reliability, such as flexible generation and responsive load, are finite. Operating practices, procedures, and tools that maximize the effective use of limited responsive resources improve reliability and facilitate variable generation integration. Operational tools can also help support and maintain the system's ERSs.

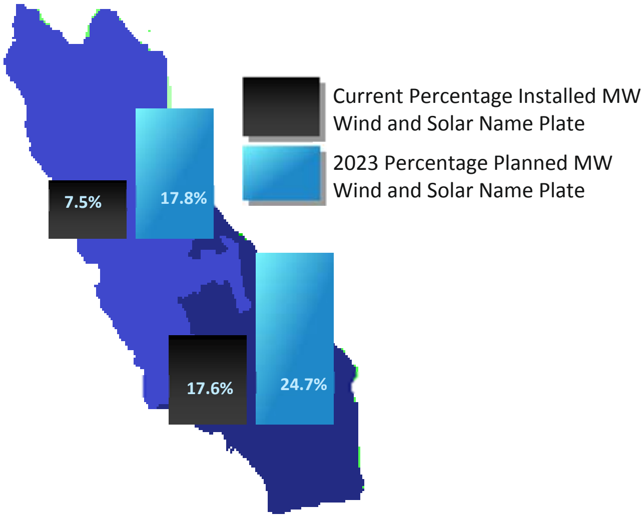

Figure 11: Current and Projected Wind and Solar Penetration in California. (Source: Ventyx)

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[11] http://www.consultkirby.com/files/NYISO_Industrial_Load_Response_Opportunities.pdf

Additional system flexibility and ERS requirements will also increase. This flexibility manifests itself in terms of the need for dispatchable resources to meet increased ramping, load following, and regulation capability, and it applies to both expected and unexpected net load changes. This flexibility will need to be accounted for in system planning studies to ensure system reliability. System planning and VER integration studies could focus both on the reliability and economic optimization of the power system.

Hawaii

Hawaii is rapidly integrating renewable resources into its power grid, as shown in Figure 12. The current capacity makes up 13 percent of the total resources with a goal to reach 40 percent by 2030. In extreme events, Hawaii uses a load-shedding scheme as an operating procedure. Part of the Hawaiian network experiences operational reliability issues due to the loss of inertia and the loss of generating units used to control transient instability. This is driven by the integration of significant non-controllable generation and the lack of sufficient attention to ERSs. A combined GE and Hawaii report on renewable integration recommended mitigation actions on frequency response and active power control with increased dependability on fast-starting generation to provide ramping capabilities.

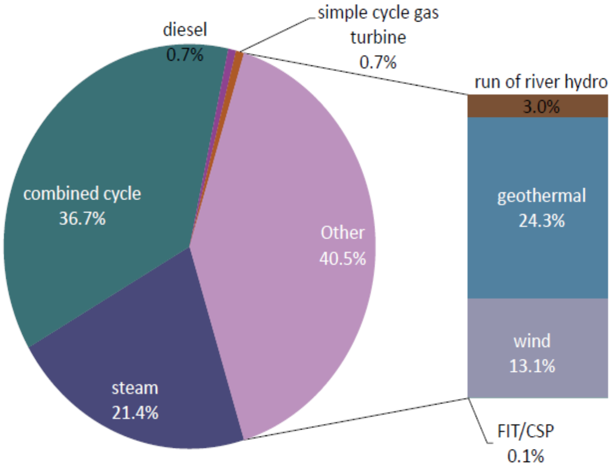

Figure 12: Resource Mix in Hawaii

Germany

In some areas of North America, it is possible that very high penetrations of variable generation could be achieved in the future, as has occurred in some regions of Germany (VTT and Dena [12]).

In recent years, electricity production from DERs in Germany increased significantly due to the German Renewable Energy Sources Act. PV power plants have shown the highest growth rates. About two-thirds of PV power plants in continental Europe are connected to low-voltage networks. Related grid codes allow for DER only to operate within frequency ranges that are, in many cases, extremely close to nominal frequency. During abnormal system conditions, the frequency of a region may increase above those ranges, and DER would disconnect immediately, posing a significant challenge for BPS performance during and after a disturbance.

In 2011, Germany was the largest European producer of variable generation, including wind, biofuel, and solar with wind serving 33 percent of peak load energy in northern Germany. Occasionally, with high winds and congestion in the transmission system, the northern German system faces supply and demand challenges. The VTT Technical Research Centre and Dena studies recommend ride-through capabilities to improve balancing requirements. Voltage and frequency ride-through requirements have since been implemented in the German grid codes for both utility-scale and DER projects, but after-the-fact measures to preserve BPS reliability have resulted in significant costs.

Texas

ERCOT has significant experience maintaining operational reliability with substantial and increasing levels of interconnected variable generation. Using a combination of state-of-the-art wind generation forecasts and flexible levels of ancillary services, ERCOT manages available wind and solar generation to support system reliability utilizing current procedures. Texas continues to develop wind farms along its coastline, and these installations

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[12] VTT Technical Research Center of Finland, "Design and Operation of Power Systems with Large Amounts of Wind Power - First Results of IEA Collaboration," http://www.ieawind.org/annex_XXV/Meetings/Oklahoma/IEA%20SysOp%20GWPC2006%20paper_final.pdf

have a slightly higher capacity factor compared to the plants sited in inland Texas and the panhandle areas. This development should increase the overall benefit from wind generation.

Given the transition of generation occurring across Texas, ERCOT has explored improvements and changes to the current ancillary services approach. These improvements capture key BPS operational needs and are in line with the ERSs discussed in this paper.

Conclusions

The North American electric system will continue to experience increased penetrations of variable resources, retirements of conventional coal and nuclear units, and increases in gas generation. These changes substantiate the need for an industry-level review of the impact to ERSs evolving from the emerging conditions. The results of this review may come in many forms, but some of them could be:

- Detailed analyses of each service with new system parameters and criteria;
- A framework for a longer-term assessment of technical parameters for each service; and
- Other solution sets for maintaining reliability that can be derived from:
    - Exploring and incorporating new technology integration, and
    - Enhancements to Reliability Standards or requirements.

Next Steps

Newly integrated technologies can be a challenge in some areas of the North American electric system. Extensive research is being conducted to evaluate what ERS functions these new technologies may provide. This research is independently conducted by subject matter experts, academia, and manufacturers. For example, certain types of wind turbine generators are equipped to provide inertia and ramping capability faster than conventional generators. However, these units are rarely installed on the BPS due to limited availability and high cost. They also may not be available or able to sustain an output at all times. Based on the current research, newly revamped NERC standards, and available electronics technology, the following are examples of possible ways to address the need for ERSs:

- Reactive Power and Voltage Control – Develop an interconnection and sub-regional voltage stability metric.
- Synthetic Inertia – Utilize synthetic inertia where available through wind farms to arrest frequency decline.
- Active Power Control, and Frequency Support – Leverage work done via NERC's Integration of Variable Generation Task Force (IVGTF) and Frequency Working Group (FWG) in developing new NERC standards and updating others.
- Ramping Capability – Establish a baseline for ramping needs and availability. Then, identify how the changing resource mix is impacting ramp availability. The difference of the ramp rate from current conditions to projected system conditions will allow for the identification of a ramping capability margin that can be utilized to ensure sufficient resources are available to provide that service. North American regions like California are exploring the possibility of flex-ramping capability to accommodate a massive influx of solar and wind power on their systems.

Other services can be quantified or analyzed by developing an assessment that will identify metrics, procedures, and methodologies to determine the need for ERSs, provide for them, and maintain them in an electric system. The assessment will focus on following:

- Engineering and technical details for each service, linked to the composition of the resource mix
- Framework for assessment of data required to measure and formulate a metric for each service
- Data collection and analysis to quantify these services

NERC, through the ERSTF, will work with entities in different NERC Regions to develop appropriate guidelines, practices, and requirements to assure the BPS benefits from the advanced capabilities of all new technologies while also assuring that reliability is maintained.

Abbreviations

Abbreviation	Term
AGC	Automatic Generation Control
ACE	Area Control Error
APC	Active Power Control
BA	Balancing Authority
BPS	Bulk Power System
CAISO	California Independent System Operator
DCS	Disturbance Control Standard
DER	distributed energy resource
DG	Distributed Generation
DR	Demand Response
ERCOT	Electric Reliability Council of Texas
ERSs	Essential Reliability Services
ERSTF	Essential Reliability Services Task Force
FC	Frequency Control
FFRS	Fast Frequency Response Service
FRT	Frequency Ride-Through
FR	Frequency Response
FWG	Frequency Working Group
IOS	Interconnected Operations Services
IVGTF	Integration of Variable Generation Task Force
LTRA	Long-Term Reliability Assessment
NG	Natural Gas
NERC	North American Electric Reliability Corporation
OATT	Open Access Transmission Tariff
OR	Operating Reserve
PV	Photovoltaic
SVC	Static Var Compensator
VER	Variable Energy Resource
VRT	Voltage Ride-Through

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