Integration of Variable Output Renewable Energy Sources – The Importance of Essential Reliability Services

Energy and Mines Ministers' Conference

St. Andrews by-the-Sea, New Brunswick

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EXECUTIVE SUMMARY

Variable renewable energy technologies (i.e., wind generation and solar photovoltaic [PV] generation) represent an attractive strategy in many provinces and territories to assist the electricity sector contribute to Canada's greenhouse gas (GHG) emission reduction commitments. Across Canada, conventional fossil fuel generating units are being retired in response to these same objectives. These changes are affecting the requirements for and availability of three "essential reliability services" (ERS) that system operators rely on to maintain reliability of the bulk electricity system. The importance of these ERS has increased given changes in the supply mix that have reduced the supply of ERS (e.g. the retirement of large conventional fossil-fuel generation units), while the introduction of large amounts of variable energy resources, which traditionally have not been configured to provide these services, has increased requirements for ERS.[1]

The purpose of this report is to provide policy makers and regulators with an overview of the ERS needed to maintain a reliable bulk power system; to identify and describe the generation sources that provide these services; and to review policy and regulatory initiatives that are being pursued to increase the number of resources that can provide these services.

These three ERS are (1) frequency support, which ensures that the electricity supply system maintains the target frequency of 60 Hz after system disturbances. Failure to maintain frequency within these boundaries can disrupt the operation of customers' equipment, initiate disconnection of power plant equipment (to prevent them from being damaged) and lead to wide-spread blackouts. Next is (2) ramping capability, which ensures that there are sufficient flexible resources that can increase and decrease output to address swings in demand; and (3) voltage support, which ensures that there are sufficient resources to maintain system voltages within an acceptable range. Voltage must be regulated in order to protect the system from damaging fluctuations, and to allocate power where needed. Reactive power is used to control voltage and enable the transmission of voltage through the electricity grid.

Reflecting the changing supply mix and the associated requirements for a broader range of generation resources to provide ERS, various wind turbine models are now capable of providing inertial response, primary frequency response, and voltage control. Solar PV projects have demonstrated their ability to provide primary frequency response, AGC, ramping services, and voltage control.

Traditionally, the costs for these services were embedded in the utility's cost-of-service or recovered through the transmission tariff. With the need for the broader provision of these services, variable energy resources must play a role in supplying them and the incremental costs for doing so must be considered. Regulators and policymakers have an important role in supporting this effort to ensure

[1] NERC, Essential Reliability Services Task Force, A Concept Paper on ERS that Characterizes BPS Reliability, October 2014, p. v. FERC, Notice of Proposed Rulemaking, Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response, p. 10-13.

that ERS are available to system operators to maintain system reliability. Regulators and policy makers in the markets with the highest proportion of variable energy resources are taking action. Recognizing the increasing amounts of wind generation in many U.S. electricity markets, the Federal Energy Regulatory Commission (FERC) has imposed requirements for wind projects to provide reactive power, which assists in supporting system voltages, and requires all generators subject to its interconnection requirements to be capable of providing primary frequency response. FERC has also allowed generators to provide primary frequency response service at market-based rates.

In Ontario, the Independent Electricity System Operator requires that large wind generators be subject to its dispatch instructions for ramping capabilities and are able to provide inertial response. California has established a new service to ensure that it has sufficient load following capability to respond to the dramatic swings in electricity requirements reflected in demand, after solar and wind output is considered. Similar actions may be required in Canada as the proportion of variable energy resources increases.

1. INTRODUCTION

1.1 Background

At the 2015 Paris Climate Conference, Canada signed an agreement to strengthen the global response to limit global average temperature rise to less than 2 degrees Celsius. Reflecting this commitment, federal, provincial, and territorial governments in Canada are working on a plan to limit carbon emissions. Variable renewable energy technologies (i.e., wind generation and solar photovoltaic [PV] generation) represent an attractive strategy in many provinces and territories for reducing electricity sector greenhouse gas emissions (GHG), particularly as increased electrification is pursued as a reduction strategy for the built environment and transportation sector.

At the same time and often for similar reasons, across Canada conventional fossil-fuel generating units are being retired. The increased penetration of variable output wind and solar PV generation, along with the retirement of these conventional fossil fueled generating units, present operability and reliability challenges. The North American Electric Reliability Corporation's (NERC) Essential Reliability Services Task Force was initiated in 2014 to analyze how changes in the North American generation resource mix impact the availability of three "essential reliability services:" frequency support, ramping capability, and voltage support. These essential reliability services (ERS) provide system operators with the tools critical to maintaining reliability of the bulk electricity system.[2] ERS are defined as the elemental "reliability building blocks" and ensure that the electrical system is able to respond to and withstand various events (e.g., the loss of major generating units or transmission facilities). The required amounts of each ERS and the resources providing them varies by region.[3]

The importance of these ERS has increased given changes in the supply mix that have tended to reduce the supply of ERS while increasing the need for these services.[4] In particular, the retirement of coal-fired and nuclear generators has reduced the supply of these services, while the introduction of greater amounts of variable energy resources as well as distributed energy resources (DER) has increased the need for ERS.[5] As more and more of these large generators are retired, there is a need to look to other sources to provide ERS. Additionally, the operating characteristics of variable energy resources are quite different from those of conventional generation types. In particular, their output is variable, and they typically have not been designed or configured to provide ERS. Further, the market and regulatory regimes in which they participate have not typically incented or required the provision of ERS. However, as discussed, increasingly these technologies are being called upon to provide ERS when technically feasible.

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[2] These ERS are more formally defined in Section 2.3.

[3] In North America ere is a common set of reliability standards that define the reliability requirements for planning and operating the North American bulk power system. These reliability standards are developed under the auspices of NERC.

[4] FERC, Notice of Proposed Rulemaking, Essential Reliability Services and the Evolving Bulk-Power System—Primary Frequency Response, p. 10-13.

[5] The role of DER is discussed in Chapter 6.

The scope of this report is focused on ERS as defined by NERC. These services are part of what is more broadly referred to as ancillary services. Ancillary services also include system protective services, loss compensation service, system control, load dispatch services, and energy imbalance services. NERC defines ancillary services as those services necessary to support a reliable bulk power system and to maintain reliable operation of the interconnected transmission system.[6]

1.2 Purpose

The purpose of this report is to provide policy makers and regulators with an overview of the ERS needed to maintain a reliable bulk power system; to identify and describe the generation sources that provide these services; and to review policy and regulatory initiatives that are being pursued to increase the number of resources that can provide these services. The report is intended to assist policy makers and regulators to understand the fundamentals of electricity planning and power system operations and the essential services that ensure system reliability.

2. MAINTAINING RELIABILITY: IMPORTANCE OF ERS

2.1 Importance of Reliability for Electricity

Electricity is a unique commodity for several reasons. First, the production of electricity must match customer demand on a continuous basis, with deviations potentially resulting in changes in frequency, which can in turn imperil the equipment that is connected to the electricity grid including motors and generators. Second, suppliers and consumers are connected with transmission facilities that are designed to operate under specific conditions and are affected by the loss of major components (generators or transmission facilities) of the bulk electricity system as well as large loads.

Electricity is a vital service and thus the reliability of electricity service is critical. Reliability is defined as the ability to meet the electricity needs of end-use customers, even when unexpected equipment failures or other conditions reduce the available power supply. Providing reliable electricity service is complicated by the fact that it requires real-time control and coordination of thousands of generators, while respecting the operating constraints of expansive transmission networks, and ultimately delivering the electricity to millions of end-use customers through local distribution systems.[7] Power system planners and operators take many factors into consideration when deciding how to maintain a reliable grid. Planners are responsible for forecasting future electricity needs (i.e., annual energy consumption and peak electricity demand), while operators ensure that resources are available to balance the electricity grid on a second-by-second basis and that resources are on standby to respond to the loss of major components.

An important aspect of system planning and operation to maintain reliability is recognizing that the output of all generation resources is not the same.[8] A generator that provides ERS is not equivalent

[6] Glossary of Terms Used in NERC Reliability Standards: http://www.nerc.com/files/glossary_of_terms.pdf
[7] http://www.electricity.ca/industry-issues/economic/reliability.php
[8] http://www.energycentral.com/c/um/all-megawatts-are-not-same

to a generator that does not. For example, a 100 MW coal-fired generator can increase or decrease its output in response to dispatch instructions from the system operator and by so doing provide ramping capability; be synchronously connected to the transmission network and provide frequency support; and be used to support system voltages. If the coal-fired generator is replaced by a 100 MW variable output wind generation project, reliability must be considered. Depending on design and regulatory requirements, the new generator may not be able to increase its output in response to a request from a system operator in order to provide ramping capability; is not synchronously connected to the grid; may not be able to provide frequency support; and may not have voltage control capability.[9]

However, current wind turbine and solar PV technologies can provide a number of these ERS. Furthermore, the integration of wind and solar PV can be facilitated with advanced planning and optimization.[10] As the proportion of wind and solar PV increases, the system operator may need the capability to curtail the wind generator or solar PV project (i.e., cause each to reduce output). A critical issue is that the wind and solar PV output are determined by available wind speeds and solar radiation, which are variable. Therefore these projects will be available to operate much less of the time, compared with a coal-fired generator, and their output will fluctuate.

2.2 Importance of ERS to Bulk Electricity System Reliability

ERS are needed to provide customers with round-the-clock delivery of electricity at the proper voltage and frequency and to ensure that the bulk power system can withstand sudden disturbances or unanticipated losses of system components, whether caused by natural or man-made events.[11] Maintaining system reliability is important for many reasons. In a reliable electricity system, there is adequate supply to meet electricity demand in all hours of the year, and the system provides acceptable power quality (i.e., stable voltages and frequency that are essential for the operation of electrical devices) for customers. In other words, electricity system reliability ensures customers can have confidence in the quality of electricity service as evidenced by few service disruptions and consistent power quality. The three keys to such service reliability are sufficient supply to meet demand, a strong network to maintain delivery to customers, and appropriate voltage and frequency to ensure that the electricity can be used. To summarize, maintaining electricity system reliability is important for the following reasons:

- Protects system components (such as generation units and transmission equipment) and electricity using equipment from damage;

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[9] A synchronous connection is one whereby a generator is operating at the same frequency as the electricity network to which it is connected. As discussed, these generators are naturally able to support system frequency through their inertial response. Some generators, including many variable output resources are connected asynchronously and as a result do not have that capability.

[10] Managing a large system with limited amounts of variable renewable energy (VRE) is not necessarily a challenge. A critical issue is the proportion of VRE to the size of the system.

[11] http://www.electricity.ca/industry-issues/economic/reliability.php

- Allows for control of the system so that it stays within acceptable voltage and frequency limits;
- Minimizes the impact and scope of electrical outages;
- Allows the system to be restored promptly following an outage (for example, as the result of a natural disaster); and
- Ensures that the system is able to supply the electrical requirements of consumers at all times, even with scheduled and unscheduled outages of system components.

2.3 Essential Reliability Services Definition

NERC identifies ERS as the essential building blocks necessary to maintain electricity system reliability.[12] These ERS are:

- Frequency Support: ensuring that the electricity supply system maintains the target frequency of 60 cycles per second or 60 Hertz (Hz) after system disturbances;
- Load Following / Ramping: ensuring that there are sufficient flexible resources that can increase and decrease output to address swings in demand; and
- Voltage Support: ensuring that there are sufficient resources to support system voltages.

These ERS are summarized in Table 1, and discussed in more detail below.

Table 1. Summary of ERS Fundamentals

Service	ERS Description	Effects of Lack of ERS Availability	Service Provided By
Frequency Support	Ensures the frequency of the bulk electricity system can be maintained and is stable for both normal and abnormal (loss of components) conditions. Resources are required to quickly engage to bring the grid back to its necessary level of 60 hertz. Controlling frequency can be broken into the following: ○ Inertial Response; ○ Primary Frequency Response; and ○ Secondary Frequency Response.	Large frequency deviations can result in equipment damage and power system collapse. Interconnection frequency deviation can result in: ○ Loss of generation; ○ Load shedding; and ○ Islanding, where segments of the bulk power system are no longer operating synchronously.	**Inertial response** typically provided by large synchronous generators (e.g., coal-fired, gas-fired, nuclear, hydroelectric) that have "spinning momentum" or large rotating masses to offset frequency disruptions. The momentum causes the generator to speed-up (with load loss) or slow-down (with generation or transmission loss) in response to a frequency disruption. **Primary frequency response** typically provided by generators' governors (e.g., primarily hydroelectric and coal-fired), which automatically respond to frequency deviations from the 60 Hz target

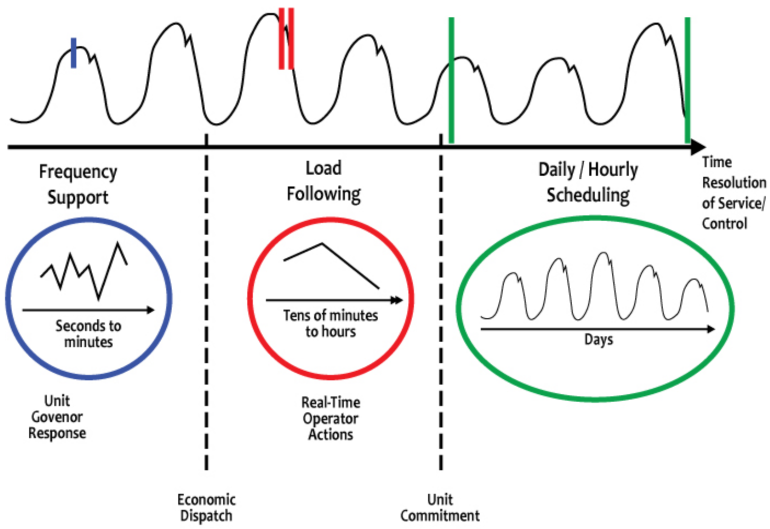
[12] http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF_Draft_Concept_Paper_Sep_2014_Final.pdf

			Secondary frequency response typically provided by generators with Automatic Generation Control (e.g., coal and gas-fired and hydroelectric units), which allows the generator to respond to second-by-second dispatch signals from the system operator to increase or decrease output
Load Following / Ramping	Daily operation of the bulk electricity system requires a continuous balancing of generation and load. Operational flexibility is needed to manage real-time changes in load and generation. Changes to the generation mix or the system operator's ability to adjust resource output can impact the ability of the operator to keep the system in balance.	System stability and reliability are at risk. Imbalance in generation and load can overload transmission facilities (surplus of generation relative to load) or cause voltage to drop (deficit of generation). Protection equipment can malfunction or be damaged.	Typically provided by peaking (e.g., simple cycle gas turbines) and intermediate generators (e.g., combined cycle gas turbines) that can ramp up and down (i.e., have available output capability or head room to increase or decrease output) and turn on rapidly to meet immediate system requirements
Voltage Support	The primary objective of voltage support is to maintain transmission system voltages within a secure, stable range. Voltage support is location-specific and requires reactive power control from resources distributed throughout the power system.	Localized voltage issues can manifest to a wide 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 overheating. Voltage collapse can lead to a cascading drop in voltage and system outages.	Controllable sources for voltage support include generators that are able to vary their reactive power output, inductive and capacitive compensators, and transformers, which are utilized to inject and absorb reactive power and keep voltage between the necessary minimum and maximum levels. These sources work in tandem with each other to provide voltage control.

Source: Modified from
http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF_Draft_Concept_Paper_Sep_2014_Final.pdf
http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERS%20Abstract%20Report%20Final.pdf,
https://vimeopro.com/nerclearning/erstf-1/video/132358336

Frequency support and load following are similar in that they both involve ensuring supply and demand are appropriately balanced. However, as illustrated in Figure 1, they focus on different time dimensions.

Figure 1. Illustration of Operational Planning Time and Services Required



Source: Adapted from NERC: Accommodating High Levels of Variable Generation

2.3.1 Frequency Support

Reliable operation of the grid requires maintaining system frequency within predetermined boundaries, which vary by system, above and below 60 Hz.[13] Failure to maintain frequency within these boundaries can disrupt the operation of customers' equipment, initiate disconnection of power plant equipment (to prevent them from being damaged), and lead to wide-spread blackouts.

Frequency support is the ERS that regulates frequency. Frequency response is the capacity of a resource to stabilize frequency following dramatic changes in load or resources, an essential capability to maintain the 60 Hz frequency. The ability of a resource to provide frequency response can be assessed in three time dimensions.

1. **Inertial response** is provided by the physical inertia of large generators as they decelerate due to the loss of generation capacity or increased electrical load (i.e., momentum of the generator, which limits the decline in frequency from the loss of generation or increase in load.)[14] Conversely, it includes the acceleration of generators from the loss of electrical load. Inertia reduces the rate of change of frequency, allowing time for primary frequency response to arrest the frequency deviation and stabilize the power system.
2. **Primary frequency response** is normally automatically controlled by generator governors

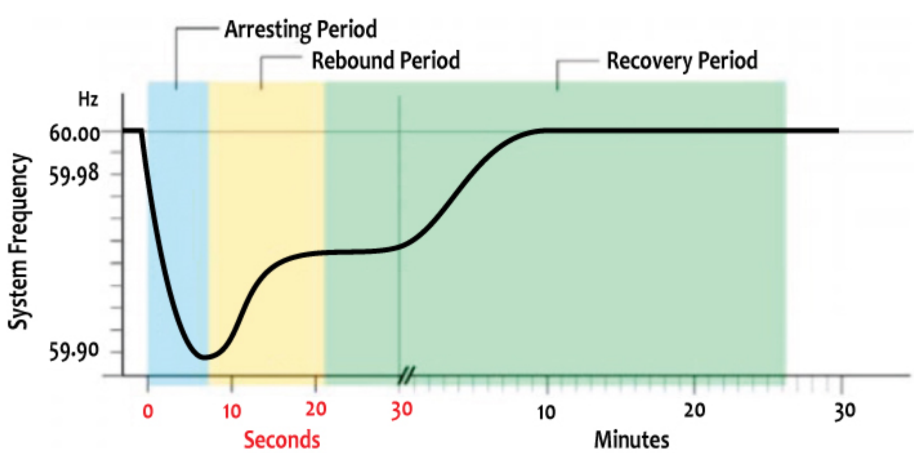
[13] 60-Hz is the frequency target for most North American electricity systems. There are small pockets of legacy systems that operate at different frequencies.
[14] Inertial response describes the ability of rotating generators (and loads) to resist changes in frequency. The less inertia a power system has the faster its frequency will fall after a loss of generation. Inertia is defined in physics as a property of matter by which it continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force.

responding directly to changes in grid frequency (i.e., generator governors sense decline in frequency and increase output). Reliable operation of the electric grid requires a sufficient amount of these automatic frequency responses (which occur within five to 15 seconds) to ensure that system frequency does not drop to the point that load is lost and generators are tripped offline. While not desirable, because it requires disconnecting customers, under-frequency load shedding can be used to prevent low frequencies that may damage grid-connected equipment or lead to broader system outages. Under-frequency load shedding is considered a primary frequency response because it can occur within seconds.

3. **Secondary frequency response** involves manually adjusting the output of individual power plants at the request of system operators, and typically takes much longer to restore system frequency (from 30 seconds to five minutes). It includes automatic generation control (AGC); it is often specified in transmission tariffs as a service for which generators are compensated and transmission customers must pay for. AGC is provided on a more extended time dimension than primary frequency response and as a result is an element of secondary frequency response.

As shown in Figure 2, frequency will immediately fall following a disturbance such as the loss of a large generating unit. This requires an instantaneous (inertial) response from some resources and a fast response from other resources to slow the rate of fall during the arresting period when primary frequency response will occur; a fast increase in power output during the rebound period to stabilize the frequency; and a more prolonged contribution of additional power (secondary frequency response) to compensate for lost resources and to bring system frequency back to the normal level.[15]

Figure 2. Frequency Fall Following Disturbance



Source: http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERS%20Abstract%20Report%20Final.pdf

[15] http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERS%20Abstract%20Report%20Final.pdf

Capability Required

To be able to provide frequency support, resources must be on line and dispatched below maximum output so that they are capable of increasing output immediately to keep demand and supply balanced to maintain the target frequency of 60 Hz. Large synchronous (synchronized with the grid) generators provide inertial frequency response by naturally speeding up or slowing down due to their inherent inertia to maintain the target frequency when a generator or transmission line trips. Wind turbines can provide inertial response if specifically configured to provide this service. Hydro-Québec TransÉnergie has required wind projects with a rated output greater than 10 MW to increase their active power output by at least 5% for about 10 seconds in response to severe frequency dips.[16,17]

Primary frequency response is mostly provided by the automatic response of turbine governors (governor response) that sense frequency changes and automatically adjust the generator's output to counteract the frequency change. Some loads can provide primary frequency response by automatically reducing demand in response to a frequency drop. Historically, virtually all generators were relied upon to provide governor response. Today, some generators, including all current nuclear generators, most wind turbines in North America,[18] as well as many new natural gas turbines, do not provide governor response. The reasons are outlined below.

Variable energy resources either do not have rotating inertia (such as solar) or can provide system inertia only if they are specially configured to do so (such as wind).[19] Other generators, which may be capable of providing governor response, are sometimes operated in ways that prevent them from providing that response (e.g., governors are disabled). For example, a generator operated at its maximum capability cannot provide upward primary frequency control because it has no ability to increase output. In competitive electricity markets, operating below maximum capability requires generators to forego revenues and adversely affects their profitability. Finally, some generators have additional controls that override the sustained delivery of governor response.[20]

California Independent System Operator (CAISO), First Solar, and National Renewable Energy Laboratory (NREL) demonstrated that a large utility-scale solar PV facility can provide primary frequency control and AGC using advanced power electronics, with the AGC performance better

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[16] Marcus Fischer, Operational Experiences with Inertial Response Provided by Type 4 Wind Turbines, p.1

[17] This capability was important to Hydro-Québec TransÉnergie because it is not synchronously connected to any other AC networks and wind generation was expected to represent about 10% of peak load and about 25% of s minimum load.

[18] While wind turbines have rotating mass which would allow them to provide inertial response, power converters that electrically connect wind turbines to the grid decouple the rotation of their turbines from the grid.

[19] See, e.g., General Electric WindINERTIA Control Fact Sheet (2009), http://site.ge-energy.com/prod_serv/products/renewable_energy/en/downloads/GEA17210.pdf

[20] https://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf

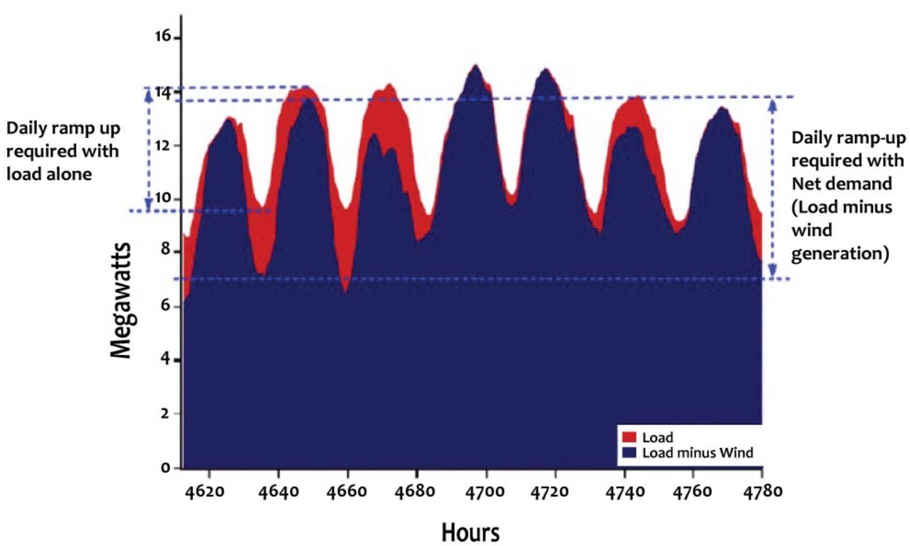
than fast responding gas turbine technologies.[21] Secondary frequency response involves changes to the output of resources on AGC (e.g., regulation resources) that respond to dispatch instructions.

2.3.2 Load Following

In order to maintain reliability, system operators must manage rapid changes in demand and supply. Load following (ramping) is the ability of a generator to change output in response to changes in demand, particularly after the output of non-dispatchable variable energy resources is considered. A facility "ramps up" to match an increase in demand to offset deficits between supply and demand or "ramps down" to curb overproduction when supply exceeds demand. Load following capability is determined in terms of minimum operating levels and ramp rate (e.g., MW/minute by which output can increase). As shown in Figure 3, increases in variable generation can result in significant increases in the requirements for load following.

As an example of how one jurisdiction is adapting to changing ramping requirements, the California electricity system operator instituted a separate market for flexible ramping products in August 2011, which became effective with the trading of the specific product in November 2016.

Figure 3. Impact of Variable Generation on Load Following and Ramping Requirements



Source: Adapted from NERC: Accommodating High Levels of Variable Generation

Load following requires a generation facility to be able to adjust output under "operations as usual" conditions at the expected ramp rate, generally on a relatively predictable schedule (e.g., morning load ramp up) with foreseen factors (e.g., daily and seasonal load patterns, as discussed in Section 4). Load following is typically provided by generating resources that are specifically designed to provide

[21] http://www.nrel.gov/docs/fy17osti/67799.pdf

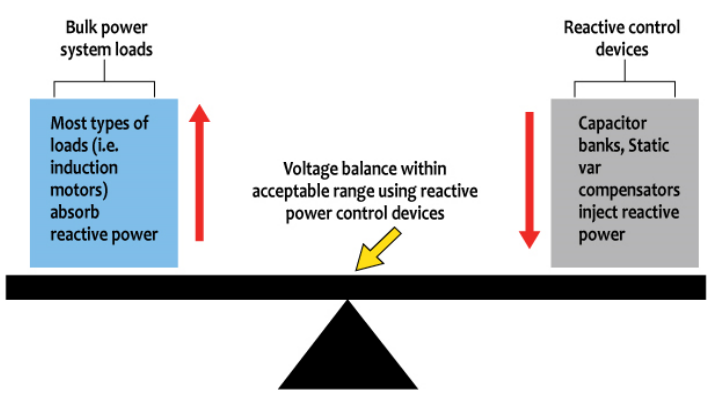
operating flexibility (e.g., fast ramp rates). Gas turbine equipment manufacturers such as General Electric and Mitsubishi have focused on designing and developing highly flexible gas turbines that are well suited to provide such load following capabilities. Wind turbines can also be used to provide this service and are called upon to do so in Ontario and Colorado.

2.3.3 Voltage Support

As illustrated in Figure 4, voltage support is necessary to balance or regulate system voltage levels within a given operating range. Voltage must be regulated in order to protect the system from damaging fluctuations, and to allocate power where needed. Reactive power is a tool used to control voltage and enable the transmission of voltage through the electricity grid.

Similar to the requirements for inertial response, Hydro-Québec TransÉnergie also imposes requirements on wind turbines in Québec to provide voltage support.[22] Specifically, wind turbines in Québec must be equipped with an automatic voltage regulation system that can supply or absorb reactive power. The voltage regulation requirements can be addressed by the wind turbine or equipment installed to provide such voltage support. Similarly, CAISO, First Solar and NREL demonstrated the ability of a large utility-scale solar PV facility to provide voltage control using advanced power electronics.

Figure 4. Illustrative Representation of Reactive Power Control



Source: http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Concept%20Paper.pdf

Reactive Support

In order to maintain specific voltage levels, reactive power devices (sometimes referred to as compensators) are used to provide or absorb reactive power. Renewable energy resources using inverter technology for interconnection can also provide this service if properly designed to adjust

[22] Martin Fecteau et al, Assessment of ENERCON WEC Grid Performance based on Hydro-Québec System Requirements: a Cooperation between ENERCON and Hydro-Québec, p. 3.

voltage at the point of injection into the grid. One of the most common forms of a reactive control device is a capacitor. To regulate voltage, such devices must be located at or near the generator or primary load centres.

2.4 Identification of ERS Contributions

Table 2 provides a further overview of each ERS by identifying the generation technologies that are able to provide each ERS, and under what conditions. Sources must be operating and on-line in order to provide ERS. Further, load following requires that a resource be operating below its maximum and above its minimum outputs to allow it to ramp up or down, respectively.

Table 2. Ability of Primary Generation Sources to Provide ERS

Technology	Frequency Support	Load Following	Voltage Support
Simple Cycle Gas Turbine	Can provide inertial response and primary response when operating. Requires AGC for secondary response.	Can provide load following. Requires start-up and must be operating at minimum load or higher, typically some efficiency loss to provide. Fast ramp rate, however.	Can provide voltage support.
Combined Cycle Gas Turbine	Can provide inertial response, but ability to provide primary response often overridden by disabling governor or operation at maximum output.	Can provide load following, Requires start-up and must be operating at minimum load or higher, typically some efficiency loss to provide. Relatively, fast ramp rate.	Can provide voltage support.
Coal-fired Generation	Can provide inertial response and primary response when operating. Requires AGC for secondary response.	Can provide load following, but ramp rate slower than many resources.	Can provide voltage support.
Hydroelectric Generation – Run-of-river	Can provide inertial and primary response when operating. Unlikely to provide secondary response given limited dispatch flexibility.	Can provide load following, dependent on resource availability. Fast ramp rate relative to other resources.	Can provide voltage support.
Hydroelectric Generation – With Storage	Can provide inertial, primary and secondary response when operating.	Can provide load following, however dependent on storage capability and spill constraints. Fast ramp rate relative to other resources.	Can provide voltage support.
Nuclear Generation	Can provide inertial response and primary response in some circumstances. Not ideal for secondary response since	Cannot provide load following. Nuclear generation optimized for consistent energy output,	Can provide voltage support.

	nuclear generation optimized for consistent energy output, therefore variation of output for frequency regulation unlikely.	therefore ramping is not available.	
Wind Generation	Can provide inertial and primary frequency support with technical modifications.	Can provide load following, dependent on resource availability. Fast ramp rate relative to other resources.	Can provide voltage support dependent on resource availability. Consistent voltage support requires energy storage component.
Solar PV Generation	Can provide inertial response and primary frequency response with appropriate components.	Can provide load following, dependents on resource availability. Fast ramp rate relative to other resources.	Can provide voltage support with appropriate components.

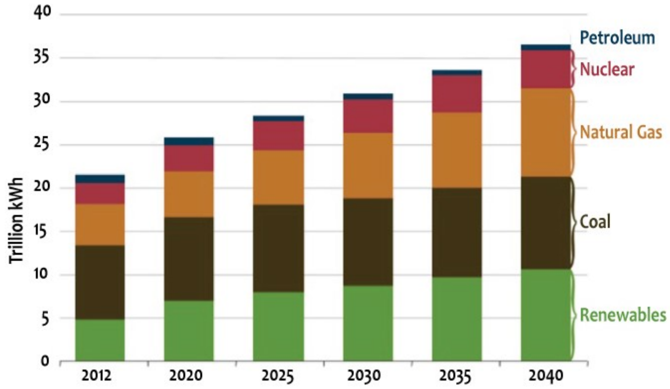
3. DRIVERS TO MAINTAIN RELIABILITY ON AN INTEGRATED GRID

3.1 Changing Supply Mix

Electricity supply has traditionally been provided primarily by fossil-fuel, hydroelectric and nuclear resources that are synchronously connected to the grid. These conventional generation resources have predictable operating performance and reliability characteristics. Accordingly, ERS have primarily been provided by these traditional power plants. However, the retirement of coal-fired, older natural gas, and nuclear generating units means that a significant proportion of the generating units that have historically provided these services will no longer be available. Furthermore, increasing amounts of variable energy resources are being added to the bulk electricity system, which tends to increase the requirements for ERS (e.g., load following as shown in Figure 3), or result in the addition of generating resources that may not be configured to provide these services (e.g., do not have rotating generators that are synchronized to the bulk power system or the ability to provide AGC). Figures 5 and 6 present the historical and future projected worldwide net electricity generation by fuel type to illustrate the extent of additional variable energy resources. In particular, Figure 6 shows the growing amount of wind and solar generation anticipated in the coming decades.

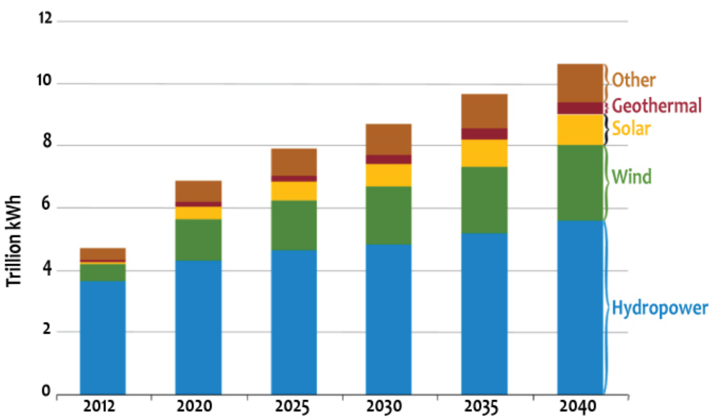
As traditional generating resources are retired and the amount of variable generation increases, ERS must be obtained from other sources besides conventional generation resources. The primary challenge for operators of the bulk electricity system is how to adapt their control philosophies and requirements to accommodate these supply changes. Operators have less knowledge and experience with the characteristics and system responses to variable energy resources on a large scale. Another challenge system operators are faced with is redesigning market rules to adapt to the increase in variable energy resources. Ontario is a good example. The IESO spent several years redesigning several key market rules in order to accommodate the increasing uptake of wind generation. This is discussed further in Section 7. Today, some variable energy resources are beginning to offer ERS capabilities,[23] but challenges remain.

Figure 5. World Net Electricity Generation by Fuel



Source: EIA Energy Outlook 2016[24]

Figure 6. World Net Electricity Generation from Renewable Resources by Resource



Source: EIA Energy Outlook 2016

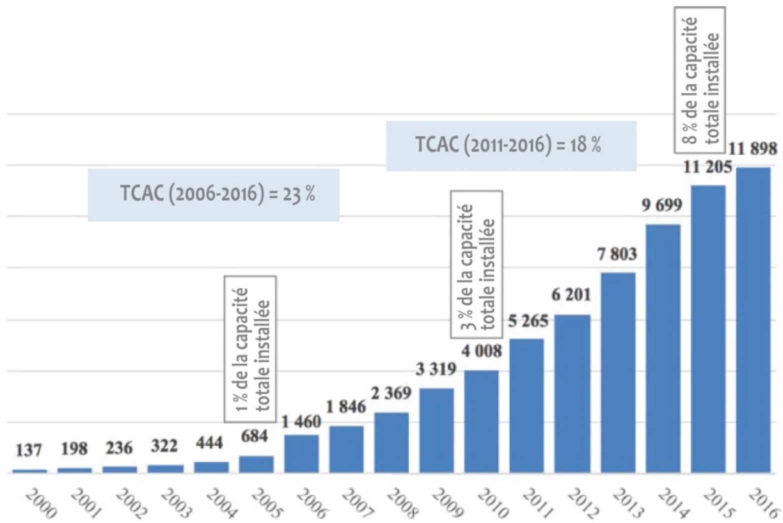
3.1.1 Trends in Variable Output Renewable Energy Adoption

Wind Generation

The amount of installed wind capacity in Canada has increased dramatically over the last decade, as shown in Figure 7 below. Correspondingly, the energy produced from wind facilities has increased as well.

[23] For example, some wind turbines now feature power electronics capable of controlling and regulating system voltage and are capable of providing inertial response and primary frequency response.
[24] https://www.eia.gov/outlooks/ieo/electricity.cfm

Figure 7. Installed Wind Capacity (MW) Growth in Canada



Source: CanWEA (http://canwea.ca/wp-content/uploads/2017/01/Canada-Current-Installed-Capacity_e.pdf)

As shown in Figure 7, wind capacity in Canada has grown by a 23% compound annual growth rate (CAGR) from 2006 to 2016. More importantly, in several provinces and regions it has a penetration rate that required changes by system operators. (See discussion in Chapter 7.) For example, Ontario continues to be the leading producer of wind energy in Canada with 4,772 MW of installed capacity (and an additional 1,284 MW of contracted wind capacity expected to come on-line within the next few years). By installed capacity, wind generators in Ontario currently represent approximately 5% of provincial electricity energy demand.[25] As a result of this significant uptake, Ontario revised the market requirements for variable output renewable resources and is considering additional reforms, as discussed in Section 7 of this report.

In P.E.I., wind generation currently provides approximately 25% of total energy requirements. P.E.I.'s ability to integrate such a high proportion of wind is facilitated by the fact that it is part of the larger NB Power control area. Within NB Power's control area, there are about 1,100 MW of wind constituting about 11% of all capacity.[26]

Alberta is also noteworthy, with 1,479 MW of installed wind capacity. Under Alberta's new climate change plan, 5,000 MW of renewable energy will be added by 2030, to offset 6,300 MW of retiring coal-fired capacity.[27] This plan also has a target of 30% renewable energy by 2030.[28]

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[25] http://canwea.ca/wind-energy/ontario/

[26] NB Power serves as the control area operator (operates the system to ensure that demand and supply remain in balance) for New Brunswick, Nova Scotia, PEI, and a portion of Northern Maine that isn't directly connected to the rest of the New England market.

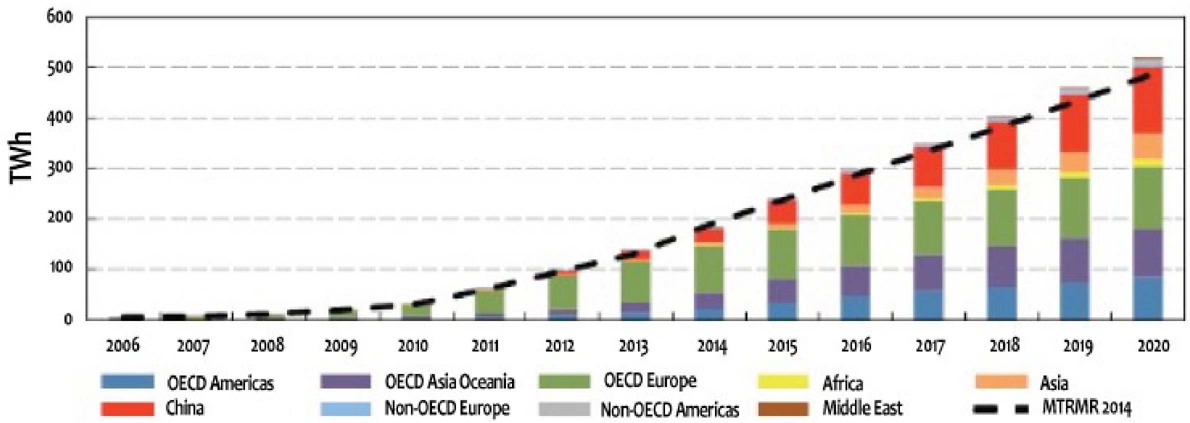
[27] http://canwea.ca/wind-facts/wind-facts-alberta/

[28] http://business.financialpost.com/news/energy/alberta-eyes-renewable-energy-boom-with-5000-megawatt-target-by-2030

Solar Generation

Similar to wind, solar PV has also experienced dramatic growth in North America. Worldwide, solar PV has increased by 46.2% per year between 1990 and 2014, making it the fastest growing source of renewable energy.[29] This trend is illustrated in Figure 8, which presents the actual and forecast amount of solar PV generation by region and year.

Figure 8. Solar PV Electricity Generation and Forecast by Region



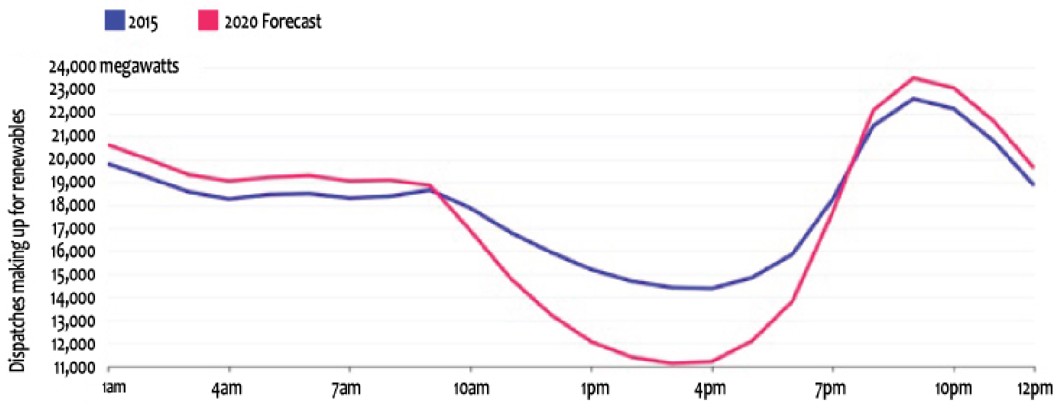
Source: http://www.iea.org/topics/renewables/subtopics/solar/

3.2 Greater Requirement for Non-Variable Generators to Vary Output

Operators do not typically have direct control over the output of variable energy resources because the wind and the sun's energy experiences natural fluctuations. As a result, energy production from wind and solar resources can vary rapidly, requiring system operators to maneuver other generation resources to balance supply and demand. This problem can be exacerbated by demand response activities (when these resources are not directly managed or controlled by system operators). The result is an increased requirement for non-variable generation to be able to respond to dispatch instructions to increase or decrease output, known as ramping and curtailment, respectively. California provides a good example of this issue. The high penetration of distributed solar generation has led the system operator to require a significant amount of ramping capability to manage the daily drop-off of solar generation in the late afternoon. This is illustrated in Figure 9, which shows the increasing ramping needs resulting from the increasing uptake of variable energy resources.

[29] https://www.iea.org/publications/freepublications/publication/KeyRenewablesTrends.pdf

Figure 9. Net Load in California After Variable Resources: the "Duck Curve"



Source: CAISO (https://www.bloomberg.com/news/articles/2015-10-21/california-s-duck-curve-is-about-to-jolt-the-electricity-grid)

3.3 Increasing Voltage Control Requirements

Recall that the voltage ratings of the various transmission and distribution system components need to be within a certain range for the electrical equipment to operate reliably and safely. Requirements for voltage control have recently been increasing to manage the fluctuating load and corresponding changes in reactive power. In order to meet these new requirements, variable resources such as wind turbines increasingly must provide this support through design changes. As discussed in Section 7, in the U.S., wind turbines now are required to provide voltage control as part of interconnection requirements.[30]

4. KEY CHARACTERISTICS OF PRIMARY GENERATION SOURCES

The characteristics of different electricity generators vary widely depending on the generator's technology type and fuel source. For example, a wind turbine's performance characteristics and operation is very different from a nuclear generator's. As a result, the ability of different generation types to provide ERS also varies widely (as discussed in Section 2). Within this section of the report, five key characteristics of primary generation sources are discussed to give further context beyond their role in providing ERS - to the considerations that system planners and operators must weigh to maintain a reliable system. These are (1) type of load served; (2) capacity rating; (3) capacity factor; (4) operational limitations; and (5) the intermittency or controllability of the generator. While not an element of maintaining system reliability, cost considerations are also critical and are discussed as well.

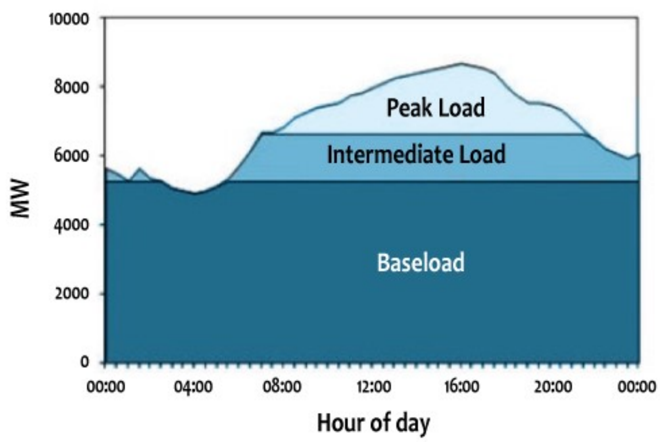
[30] NERC, "Accommodating High Levels of Variable Generation" 2009, p. 22-23 http://www.nerc.com/files/ivgtf_report_041609.pdf

4.1 Load Served

In order to meet fluctuating electricity requirements throughout the day, different types of electricity generators are required. The three general categories of generation can be classified according to the type of load that they serve: [31]

1. Baseload generators, which typically operate 24/7;
2. Intermediate generators (also referred to as "load following" generators), which typically vary output in response to changing demand; and
3. Peak generators (also referred to as "peakers"), which operate for a relatively limited number of hours, typically during peak demand periods or in response to system contingencies (e.g., loss of a major generating unit or transmission line that requires an immediate response).

Figure 10. Baseload, Intermediate Load and Peak Load



Source: http://instituteforenergyresearch.org/electricity-generation

As illustrated in Figure 10 above, baseload demand refers to the relatively constant level of demand for electricity throughout the day. Generators serving this type of demand operate at relatively constant levels throughout the day. Intermediate demand represents the additional electrical load that is not needed around the clock, but is required for the majority of the day. Generators serving this type of demand can ramp up or down as electricity demand requires, however they are most efficient when they operate for several hours in a row. Peak load generators may only operate a few hours per day, and in some cases, only the few highest demand hours per year (typically hot summer afternoons when air conditioners are running, or cold winter mornings and evenings when heating requirements are highest). The following table identifies the types of generators that are used to meet each type of demand throughout the day. Variable energy resources are unique in the sense that their ability to meet electricity demand depends on the availability of fuel (wind for example). The unique operating characteristics of variable energy resources were described in Section 3.

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[31] http://instituteforenergyresearch.org/electricity-generation

Table 3. Load Served by Different Generation Types[32]

Load Served	Description	Characteristics	Typical Generation Types
Baseload	These types of generators provide large amounts of reliable, low variable cost power but typically do not ramp up or down efficiently and often have long start times.	Low operating cost, but higher initial capital cost,can operate for longer periods.	Run-of-river hydroelectric, nuclear, and coal.
Intermediate	These types of generators can ramp up or down, are designed to start and stop repeatedly, but are most efficient when they operate for a number of hours.	Moderate operating costs, can operate for longer or shorter periods, may or may not respond quickly.	Natural gas combined cycle,* coal, oil, storage hydroelectric with higher overall output levels, wind, solar.
Peak	These types of generators can start up quickly and rapidly increase or decrease their power output.	High operating costs, quick start, fast synchronization to the grid, should be faster in taking up the system loads, respond to the load variations.	Natural gas simple cycle gas turbine, oil steam, storage hydroelectric.

*Natural gas combined cycle plants, one of the most common intermediate generation types, can ramp relatively efficiently. However, this is not the case for all typical intermediate-load generation types.

There are emerging opportunities for variable energy resources to pair with energy storage facilities to serve additional load types. The role of energy storage to help maintain system reliability is discussed in Section 6.

4.2 Capacity Rating

System operators also must know the capacity rating of a generation facility. Capacity rating is defined as the maximum sustained electric output of a generator, generally expressed in megawatts. Nameplate capacity, the maximum output identified by the manufacturer of a generation technology, is a commonly used term to describe capacity rating.[33] System operators also use seasonal capacity ratings (i.e., summer and winter), given that generator output can be affected by temperatures (e.g., gas turbine outputs decline in summer given lower temperature differentials).

4.3 Capacity Factor

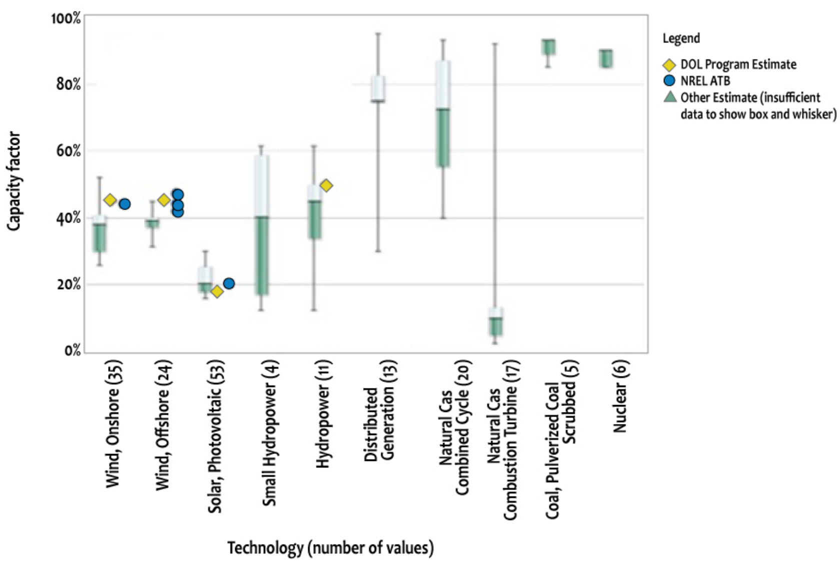
Recognizing that electricity generators do not operate at their full capacity rating all the time, the capacity factor refers to the ratio of the actual output of a generation resource to the potential

[32] Adapted from http://instituteforenergyresearch.org/electricity-generation

[33] "Installed capacity" or simply "capacity" are alternative names for the nameplate capacity of a generation source.

output if the plant operated continuously at full capacity. Therefore, capacity factor is expressed as a percentage. The following figure presents capacity factor ranges for a variety of technologies. As indicated in the figure, nuclear and coal-fired generation can have capacity factors of over 90%, meaning they are operating at their maximum capacity most of the time. On the other hand, wind and solar generators have average capacity factors of approximately 40% and 18% respectively, which reflects the fact that the resource for these generation types varies. Natural gas combustion turbine (simple cycle gas turbine) capacity factors are low because they have high operating costs, making them generally uneconomical to operate at higher capacity factors.

Figure 11. Capacity Factors of Utility-scale Generation Technologies



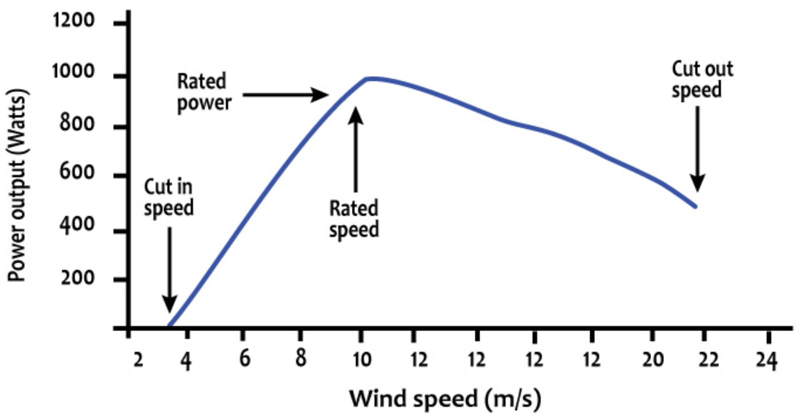
Source: Adapted from NREL 2013 "Utility-Scale Capacity Factors http://www.nrel.gov/analysis/tech_cap_factor.html?print

4.4 Operational Limitations

Operational limitations refer to the conditions that are required for a generation source to operate. For example, system operators must consider that resources such as nuclear generators cannot go below a minimum level of output and continue to produce electricity (referred to as "minimum loading point"). Wind generators also have "cut-in" speeds below which they don't operate.[34] The cut-in speed is typically 11 to 14 kmh. More importantly, wind generators have "cut-out" speeds above which they risk damage from continued operation. The cut-out speed is typically 5 to 6 times the cut-in speed. In addition, system operators will need to ensure that the fleet of operating and available resources can provide the required mix of ERS as well as other ancillary services that are needed to reliably operate the system.

[34] For example, during a stakeholder engagement process in Ontario, wind generators indicated that they have a technical preference against operating wind turbines below 10% of their available output.

Figure 12. Illustrative Wind Generator Cut-in and Cut-out Speeds



Source: http://www.build.com.au/wind-speed-cut-and-cut-out
Note: Power output and cut-in and cut-out speeds are illustrative. These are turbine specific. Utility-scale wind turbines currently are considerably larger.

4.5 Variability/Controllability

A final key consideration of system operators managing the electricity system relates to how and when a generator is available for use. This concept becomes especially important when considering how best to meet the demand for electricity throughout the day (as discussed in Section 4.1 above). Variability versus controllability describes the ability of the system operator to schedule or dispatch the generation resource. For example, although their availability can be predicted, variable resources (i.e. wind and solar generators) are dependent on factors outside of the control of the generation facility operator. In the case of a wind generator, wind conditions limit when and how much electricity can be produced. On the other hand, controllable resources (such as gas-fired, coal-fired, and nuclear generators to a lesser degree than the others) can be turned on or off and can have output adjusted based on instructions from the system operator. For this reason, a common term for controllable generation sources has been dispatchable generation. The concept of dispatchability, in the context of an Ontario-specific example, is discussed in Section 7.2.1.

4.6 Cost Considerations

System operators dispatch and operate generating resources on the basis of operating costs, with the lowest operating cost resources typically dispatched first and with progressively more costly units dispatched as electricity requirements increase. The operating cost considerations must also include the supply of ERS and those resources that are able to provide these services at the lowest cost. This can include reducing the operation of variable energy resources, even though they have low variable operating costs, so that they are able to supply ERS when needed.

Recognizing limitations on their available output, storage hydro facilities are typically scheduled to operate during peak demand periods or when their output is most valuable. In addition, system operators have to consider the operational limitations such as minimum load levels and start times.

Similarly, system planners must consider costs of future generation sources. In addition to the capital cost of each generation resource, consideration must be given to the cost of supplying ERS.

4.7 Summary of Key Characteristics of Generation Resources

The following table summarizes the key characteristics of primary generation sources for a variety of technology and fuel types.

Table 4. Characteristics of Primary Generation Sources

Technology /Fuel	Load Served	Typical Size (MW)	Typical Capacity Factor (%)	Operating Limitations	Variable or Controllable
Simple Cycle Gas Turbine	Peak	100-200	5-10	Generally very flexible, fast ramp rate	Controllable
Combined Cycle Gas Turbine	Intermediate	250-500	30-55	Generally flexible, but with minimum loading rate, moderate ramp rate	Controllable
Coal-Fired Generation	Baseload, Intermediate	300-600	50-85	Constrained by minimum loading point, and moderate ramp rate	Controllable
Run-of-River Hydroelectric Generation	Baseload, As available	125-500	40-60	Constrained by minimum flow requirements for fish protection	Variable
Storage Hydroelectric Generation	Baseload, Peak	125-500	15-60	Constrained by minimum flow requirements for fish protection	Controllable
Nuclear Generation	Baseload	1,000	90	Constrained by minimum loading point, low ramp rate	Controllable
Wind Generation	As available	50-200	35-45	Requires wind speeds of from about 14 to 70 km/h; also shut down in cold weather (i.e. below -30 degrees C) and potentially during icing conditions	Variable
Solar PV Generation	As available	10-100	20	Constrained by solar radiation and as a result daylight and seasonality	Variable

Note: Typical Size based on U.S. capacity figures (Nameplate capacity)
Source: http://www.eia.gov/electricity/annual/html/epa_04_03.html

5. THE IMPACT OF DISTRIBUTED ENERGY RESOURCES ON RELIABILITY

Power system planners and operators are currently adapting to significant changes in the supply mix; this includes smaller distributed energy resources that are connected to distribution systems and directly to customers' facilities. When system operators are assessing the reliability of the bulk electricity system, their scope does not directly include equipment and facilities used in the local distribution of electricity. At the distribution level, the impacts of distributed energy resources (DER) are evolving and are being tracked by distribution utilities. However, these impacts to the bulk electricity system have been studied less. Similar to challenges that system operators are experiencing with integrating greater amounts of variable energy resources on the grid, reliably integrating greater amounts of DER also presents several challenges, along with opportunities. Therefore, advances in DER must be evaluated by system operators in terms of their impact on the wider electricity system and on maintaining reliability.

5.1 Definition

DER are small power generators connected to the distribution system and include a wide range of technologies and types. The predominant types of DER are described in the following table consistent with definitions employed by NERC.

Table 5. Description of DER Types

DER Application	Description
Distributed Generation (DG)	Any small electricity generating units that are connected to the distribution system or at the customer site. For example, solar panels on a residential rooftop or small cogeneration at a customer site.
Behind The Meter Generation (BTMG)	A generating unit or multiple generating units at a single location (regardless of ownership), of any size, on the customer's side of the retail meter that serve all or part of the customer's retail load. All electrical equipment from and including the generation facility to the metering point is considered to be behind the meter. For example, electricity from a residential rooftop being fed into the main electrical panel and from there to the utility grid or to be used in the home/building.
Energy Storage Facility (ES)	An energy storage device or multiple devices at a single location, on either the utility side or the customer's side of the retail meter. May be any of various technology types, including battery, flywheel, or other storage technologies.
Micro-grid (MG)	An aggregation of multiple DER types behind the customer meter at a single point of interconnection that has the capability to operate independently. May range in size and complexity from a single "smart" building to a larger system such as a university campus or industrial/commercial park.

Cogeneration	Production of multiple forms of energy including electricity, steam, heat, or other forms of energy with electricity as a by-product. For example, a hospital cogeneration plant could produce some of the power and all the hot water needed for its laundry and hot water system from the waste heat it generates.

Source: http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/Distributed_Energy_Resources_Report.pdf

5.2 Advantages

DER are seen as integral components of future modern grids. Increasing amounts of DER will change how the distribution system interacts with the bulk electricity system as a whole, and may transform distribution utilities into active sources of both energy and ERS.[35] DER implementation can offer the added benefit of furthering climate and environmental goals by displacing fossil fuel-dependent electricity generation such as coal and gas-fired generation. It can also improve resilience to outages, as power generation from DER systems is not in a concentrated region or facility. DER can defer the need for transmission and distribution system investment by reducing electrical losses and lowering the demand for electricity on the bulk electricity system.

5.3 Challenges

DER at low penetration levels do not necessarily present a risk to the reliability of the electrical system. However, as penetrations increase, shifting from synchronous, centralized generation to a more varied, heterogeneous combination of technologies, may provide challenges to overall reliability if not implemented and monitored properly.

DER can result in (1) increased requirements for ramping where the DER resources are solar PV; and (2) greater voltage swings by reducing loadings on distribution and transmission lines. Furthermore, an unexpected loss of aggregated DER can cause frequency and voltage instability at higher DER penetrations. Also, variable output from DER can contribute to ramping and system balancing challenges for system operators who typically do not have control or observability of the DER. While modeling can be used to predict changes in temperature, wind speed, and solar radiation that affect electricity demand and output of variable energy resources, the dispersed nature of DER results in a greater susceptibility to uncertainty given the lack of visibility of distribution system operating conditions by system operators. A degree of predictability – or a series of tools capable of responding to abnormal changes in energy demand or supply – is necessary to ensure reliable grid operation.

5.4 Role of Smart Inverters

Energy produced by DER can be directly connected as synchronous generators or by using inverter technology. Smart inverters have the capacity to lessen the effects of variations in DER energy output on distribution system voltages and mitigate resulting voltage fluctuations. By supporting voltage and ride-through (i.e., the ability to continue to operate with changes in voltage), inverters

[35] http://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/Distributed_Energy_Resources_Report.pdf

can guarantee a regulated, constant voltage throughout systems that have high proportions of wind turbines and solar arrays.

Smart inverters increase the grid's effective hosting capacity for DER energy. The technology can ensure the reliability of feeder systems, which are the distribution network designed to transmit energy in one direction: towards customers. Inverters allow the energy produced by DER to be able to travel in the opposite direction, and flow into the distribution system.[36] In addition, smart inverters can offer dynamic compensation to provide reactive power to reduce voltage fluctuations and maintain supply/demand balance. Micro-grids rely on smart inverters to optimize the operation of available resources with local electricity loads.

5.5 Managing Increasing Amounts of DER

Widespread implementation of DER requires structured forecasting of DER output and loads on the host distribution network, greater visibility regarding the operation and status of the DER, modeling of these distribution networks, and ensuring their proper integration to the distribution network. This may require changes to the infrastructure, operating procedures, and market rules that apply to the grid and generators. DER also require additional management and education efforts to operate multiple stations, as well as a more nuanced understanding of regional energy needs to better shape generator services.[37]

6. OTHER APPLICABLE TECHNOLOGIES THAT CAN PROVIDE ERS

This section focuses on new and innovative technologies that are being deployed to provide ERS. Energy storage technologies are receiving broader application and adoption given reductions in cost, performance improvements, and new applications of the technologies.[38]

These energy storage technologies are able to provide ERS. They have the ability to withdraw electricity from the grid during times when there is a surplus and re-inject it later when customer demand for electricity is high and to provide ramping service, frequency support, and voltage control.

6.1 New Storage Technologies

Storage technologies are being widely deployed in a number of jurisdictions to provide ERS. The two primary types of energy storage being used on the bulk power system are battery storage and flywheel technology.[39] Batteries can provide ERS as they can quickly adjust their input or output, which is required for ramping and frequency control. Flywheels are well-suited for frequency

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[36] Trabish. "Smart inverters: The secret to integrating distributed energy onto the grid". UtilityDIVE. 4 June 2014. http://www.utilitydive.com/news/smart-inverters-the-secret-to-integrating-distributed-energy-onto-the-grid/269167/

[37] http://www.sciencedirect.com/science/article/pii/S1364032105000043

[38] The role of storage hydro facilities in the provision of ERS is discussed in Chapter 4 and not repeated here.

[39] Flywheels use rotational energy in the form of a spinning mass or rotor to store energy. By increasing the speed of the rotor they can withdraw energy from the grid and store it in the form of rotational energy and then inject energy into the grid drawing upon the rotational energy of the rotor.

response. These technologies are also capable of providing voltage control with the necessary modifications and equipment.

Such technologies are being brought onto systems to provide ERS, with a notable case being the PJM Interconnection (PJM) Dynamic Regulation D signal that has enabled the development of significant amounts of energy storage.[40] In response to an order[41] of the U.S. Federal Energy Regulatory Commission (FERC, further discussed in Section 7), PJM developed the Regulation D price signal that rewards fast responding storage projects. Ontario provides another example of storage technologies contributing to ERS. In 2012, the Independent Electricity System Operator (IESO) began to contract for regulation services with flywheels and battery storage facilities. Through this program, the IESO procured 6 MW from two energy storage facilities specifically for regulation service. Recognizing the potential benefits of energy storage in providing these services and of promoting the adoption of storage technologies, Ontario's 2013 Long Term Energy Plan established a goal of procuring 50 MW of energy storage. Through a first phase of the Grid Energy Storage Procurement in 2014, the IESO selected five projects representing approximately 34 MW of energy storage to provide regulation service and/or reactive support and voltage control for a 3-year period. The majority of these projects are expected to be on-line by mid-2017, with the first coming into operation in late 2016.

6.2 Flexible AC Transmission Systems

Flexible AC Transmissions Systems, or FACTS, are another technology used to increase grid reliability. These include power-electronics based technology and controllers that enable fast responding voltage control through rapid supply of inductive (consuming) reactive power or capacitive (supplying) reactive power. Reactive power prevents large voltage fluctuations that can result in power outages, so with FACTS, transmission is made more reliable and can also be made more efficient. FACTS are a compilation of different technologies that together enhance reliability and controllability. A static VAR compensator (SVC) is a type of FACTS technology with no significant moving parts, which can be applied to transmission and industrial voltage control uses by providing fast-acting reactive power.

6.3 Demand Response

Demand Response (DR) reduces system peak loads by inducing consumers to switch energy use to lower demand periods. DR resources can be called upon when frequency drops after a generator outage and by so doing assist in restoring frequency.

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[40] PJM Interconnection is a regional transmission organization that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia.

[41] FERC Order No. 755

Table 6. Summary of Other Applicable ERS Technologies

Technology	Description	Possible ERS Provided	Example / Case Study
Storage	Allows energy to be withdrawn during times of surplus and re-injected when needed	Regulation Services, Ramping, Voltage Control	IESO Energy Storage Procurement Framework
FACTS	Devices that enhance control and stability to increase AC power transfer capabilities	Frequency Support, Voltage Control	EPRI and the New York Power Authority's 2003 coordinated control[42] of two FACTS controllers used to pull power off one line and deliver it down another
Demand Response	Consumer changes to reduce energy when demand for electricity is high	Frequency Control, Voltage Control	IESO Demand Response Pilot Program & Capacity-Based Demand Response

7. REGULATORY INITIATIVES

A number of regulatory initiatives have recently been implemented to increase the availability of ERS. Before discussing these regulatory initiatives, it is useful to discuss the regulatory and administrative framework to establish the reliability standards that are the foundation for the reliable operation of the North American bulk electricity system (also referred to as the bulk power system).

NERC was certified as the Electric Reliability Organization (ERO) for the United States in 2006. The development of a standard (or modifications to an existing standard) can originate from within NERC, or NERC can be directed to develop a standard by FERC if vulnerabilities are identified.[43, 44] Following a balloting process, standards are presented to the NERC Board of Trustees (three of these Board members are Canadian representatives) for final approval before filing with FERC.[45] Once approved, these reliability standards become mandatory and may be enforced by NERC in the United States, subject to FERC oversight.

In Canada, recognition of NERC as the ERO, adoption of NERC Reliability Standards, and the establishment of measures to monitor and enforce the standards are carried out at the provincial level. Provinces and the National Energy Board (in the case of international interties) have established processes regarding the acceptance and adoption, rejection, or tailoring of NERC

[42] For more information see http://spectrum.ieee.org/energy/the-smarter-grid/flexible-ac-transmission-the-facts-machine
[43] FERC regulates the interstate transmission of electricity, natural gas, and oil and in this capacity has broad scope over wholesale electricity markets and policies in the U.S.
[44]https://www.ferc.gov/legal/staff-reports/2016/reliability-primer.pdf
[45] http://www.nrcan.gc.ca/energy/electricity-infrastructure/18792

approved standards in their jurisdictions. As in the U.S., once adopted, the standards are mandatory and enforceable.

7.1 FERC Initiatives

In its order that established open access transmission,[46] FERC defined a range of ancillary services that encompasses some of the ERS. FERC has issued a number of orders regarding the provision of these ancillary services including some of the ERS. Drawing upon the work done by NERC's Essential Reliability Services Task Force, FERC has expressed concern that the anticipated retirement of large numbers of baseload, synchronous resources combined with the addition of more distributed generation, demand response, and variable energy resources like wind and solar, will reduce the availability of ERS within some interconnected systems.

Order No. 819

In November 2015, FERC released a final rule permitting the sale of primary frequency response (as described in Section 2) services at market-based rates. The goal of this rule was to provide an incentive for the provision of these services and to foster competition in their sale. On the same day, FERC eliminated wind turbines' exemption from reactive power requirements (also discussed in Section 2). Wind generators are therefore mandated to provide reactive power to ensure reliability of the transmission system and enhance efficiency.[47]

February 2016 Notice of Inquiry and November 2016 Notice of Proposed Rulemaking

In February 2016, FERC released a Notice of Inquiry (NOI) seeking commentary on the reform of rules and regulations pertaining to the compensation and provision of frequency response.[48] With the retiring of baseload units (as described in Section 4) and increasing amounts of variable energy resources, FERC noted that new sources of primary frequency response were required. The NOI requested input to determine the necessity of making amendments to the Large Generator and Small Generator Interconnection Agreements to require frequency response capabilities for new generation resources including variable energy resources. It also sought to clarify the importance and feasibility of potentially establishing frequency response requirements for existing resources, and creating compensation and procurement mechanisms for primary response.[49]

Following the aforementioned NOI, a November 2016 FERC Notice of Proposed Rulemaking (NOPR) introduced new requirements to ensure more robust and widespread primary frequency

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[46] FERC Order 888 mandated the unbundling of electrical services and the separation of marketing functions for these newly-disaggregated services, required utilities to provide open access to their energy rate schedules, and gave existing utilities who may have made substantial investments based on older regulations the right to recover their stranded costs from energy customers.
[47] https://www.ferc.gov/media/news-releases/2015/2015-4/11-19-15-E-1.asp#.WMnibmPQif4
[48] Essential Reliability Services and the Evolving Bulk-Power System – Primary Frequency Response, Notice of Inquiry, 154 FERC ¶ 61,117 (2016) (Frequency Response NOI).
[49] https://www.ferc.gov/media/news-releases/2016/2016-1/02-18-16-E-2.asp#.WMnh3GPQif4

response. FERC's NOPR proposed adding a mandate to the Large Generator and Small Generator Interconnection Agreements (LGIA, SGIA) necessitating that as a precondition of interconnection, all new generating facilities (both synchronous and non-synchronous) possess primary frequency response capability.[50]

7.2 Other Initiatives

Outside of FERC, individual system operators are also turning to regulatory reforms in order to help adapt to a changing supply mix. As the province with the largest number of electricity customers in Canada, Ontario provides several good examples of these regulatory reforms.

The IESO is responsible for power system planning and administering Ontario's market rules that govern the operation of the electricity market. Ontario's original wholesale electricity market design did not anticipate the high levels of variable generation. Therefore, wind generators in Ontario were traditionally considered "intermittent" generators, meaning they were not subject to the same rules as other generators such as natural gas-fired and nuclear generators. Instead, wind generators were treated as "must-run" units, and they were free to inject energy into the Ontario electricity grid. Wind generators were subject to very limited compliance rules regarding energy production, and did not receive dispatch instructions (i.e. instructions to increase or decrease the amount of electricity being produced) from the IESO. However, in response to the *Green Energy and Green Economy Act* [51](2009), Ontario experienced a dramatic increase in the amount of variable energy resources on its electricity system.

As a result, in 2011 the IESO began redesigning the market rules in order to adapt to the increase in variable energy resources (particularly wind). The market rule redesign was completed in September 2013, when large wind generators (i.e. those who were connected to the transmission system) lost their 'intermittent' designation, and became known as "variable" generators,[52] meaning they were now going to be subject to dispatch instructions from the IESO. Effectively, the IESO is now able to use these larger wind projects to provide a ramping service, if needed. As part of this change, requirements were implemented for all variable generators to provide the IESO with operational and meteorological monitoring data for the purpose of centralized forecasting, which ultimately facilitated the IESO's ability to reliably manage the system with increasing penetration of these types of resources.

Ontario Desire for Increased Flexibility of Resources and Forecasting Improvements

More recently, the IESO has identified the need for even more flexibility from both variable energy resources and non-variable resources, as well as the need for an improved forecasting methodology

[50] https://www.ferc.gov/media/news-releases/2016/2016-4/11-17-16-E-3.asp#.WMpUymPQif4

[51] Bill 150: the *Green Energy and Green Economy Act*, 2009 expanded Government authority to more directly ensure the development of demand-side resources and renewable energy supply with an emphasis on creating 'green' jobs.

[52] Variable generation means all wind and solar photovoltaic resources with an installed capacity of 5MW or greater, or all wind and solar photovoltaic resources that are directly connected to the IESO-controlled grid.

so that the IESO can more appropriately dispatch wind and solar resources according to resource availability. The specific requirements that have been identified relate to load following (as described in Section 2). Between 2017 and 2018, the IESO estimates that up to 1,000 MW of ramping capability will be demanded by the system. Through a public stakeholder engagement process called Enabling System Flexibility, the IESO is currently investigating ways to procure more flexibility in order to address the increased ramping needs.

Ontario Requirements for Primary Frequency Response

The IESO also amended its market rules to require wind projects greater than 50 MW to provide primary frequency response. These requirements are reviewed as part of the System Impact Assessments that are performed as part of the interconnection process. If this capability is determined to be commercially unavailable for the wind turbine, the requirement is not enforced. Clearly, imposing different requirements on different wind turbines is problematic.

8. OBSERVATIONS AND FINDINGS

ERS play a critical role in ensuring the reliability of our electricity supply. However, as large conventional generators are retired, the supply of these various ERS is being reduced at a time when the amount of variable energy resources (in particular, wind and solar PV), which historically have not provided these services, is increasing. Furthermore, in some markets this increase is resulting in a corresponding increase in the requirements for ERS. Given their critical role in ensuring system reliability, it is important that sufficient amounts of ERS are available to the system operators who rely on them to ensure reliability and maintain power quality. Finally, when comparing the costs of conventional and variable energy resources, proper consideration needs to be given to the provision of ERS. These costs may include additional capital costs for variable energy resources so that they are able to provide ERS, as well as increased operating costs as may be required to ensure that sufficient ERS are available.

As discussed, wind turbines are increasingly being relied upon to provide ERS. There are requirements in Quebec and Ontario for larger wind projects to provide inertial response and primary frequency response. Hydro-Québec TransÉnergie and FERC require wind turbines to be able to provide reactive power for voltage control. The actions in these jurisdictions may be models for others with an increasing penetration of variable energy resources.

DERs also present new challenges and offer opportunities to provide ERS. Solar PV systems that are located behind the meter and other distributed generation resources can change how the distribution system interacts with the bulk electricity system and result in the distribution system serving as a source of energy and ERS for the broader bulk electricity system. However, for this to happen without adverse impacts on system reliability, system operators require greater visibility and control over the operation of these resources. In addition, planning regarding future DER penetration levels and operating modes is required. Finally, new interconnection requirements may be required for DERs.

Regulators and policymakers have an important role in supporting this effort to ensure that ERS are available to system operators to maintain system reliability. Regulators and policy makers in the markets with the highest proportion of variable energy resources are taking action. In the U.S., recognizing the increasing amounts of wind generation in many U.S. electricity markets, the FERC has imposed requirements for wind projects to provide reactive power, which assists in supporting system voltages and required all generators subject to its interconnection requirements to be capable of providing primary frequency response. In addition, system operators, including Ontario's IESO, are mandating that variable energy resources (including wind) operate more flexibly to reduce requirements for load following. California has established a new service to ensure that it has sufficient load following capability to respond to the dramatic swings in electricity requirements reflected in demand, after solar and wind output is considered. Similar actions may be required in other jurisdictions as the proportion of variable energy resources increases.

APPENDIX A – GLOSSARY OF TERMS

Active Power Control – The ability to control power output of a given electric resource.

Ancillary Services – 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.

Bulk Power System – (A) facilities and control systems necessary for operating an interconnected electric energy transmission network (or any portion thereof); and
(B) electric energy from generation facilities needed to maintain transmission system reliability.
The term does not include facilities used in the local distribution of electric energy.

Capacity Rating – The maximum output that a resource (machine, system, piece of equipment) may produce and still operate correctly. Also known as nameplate capacity.

Capacity Factor – The ratio of a generating unit's produced electrical energy during a specific time period, relative to the hypothetical maximum amount of produced electrical energy under full power operation conditions during the same time period.

Distributed Energy Resources (DERs) – Smaller, decentralized power sources that may be aggregated to provide similar services and satisfy similar energy demands as a conventional centralized system. Often includes various renewable energy technologies.

Essential Reliability Services (ERS) – Operational services provided by conventional generation that are critical to sustained grid reliability. Includes the provision of frequency support, voltage support, and load and resource balance.

Federal Energy Regulatory Commission (FERC) – The independent agency entrusted with monitoring interstate electricity transactions, wholesale electricity rates, oil and gas pipeline rates, and licensing and certification of hydroelectric and natural gas projects. Exists within the national Department of Energy.

Frequency Response – The automatic corrective response of the system, typically provided by synchronous generation for balancing demand and supply.

Inertia – The stored rotating energy in a power system provided by synchronous and induction generation.

Kilowatt – A measure of electricity equal to 1,000 watts.

Load and Generation Forecasting – The tools used to predict demand and non-dispatchable resources in a variety of time frames ranging in time period from real time to several decades.

Load Following – The ability to adjust power output as demand for electricity ramps throughout the day.

Minimum Loading Point – A generation technology's minimum output level at which operate reliably.

North American Electric Reliability Corporation (NERC) – A non-profit corporation that establishes and maintains necessary reliability standards within the bulk electric system. Comprised of interconnected power regions and the regional reliability bodies that serve them, spanning the United States, Canada, and Mexico.

Reactive Power and Voltage Control – The ability to control the production and absorption of reactive power for the purposes of maintaining desired voltages and optimizing transmission and generation real-power losses.

Regulation – A service that corrects for short-term fluctuations in electricity use that might affect the stability of the power system.

Synchronous Generators **–** Energy generators that are synchronized with the grid and are readily available to provide ancillary services in the event of unforecasted changes in load or generation.

Variable Generation – Generation resources (typically renewable) whose primary fuel may vary widely and unpredictably, thus causing fluctuations in power availability, frequency, and voltage.

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