Annual Planning Outlook

Operability

March 2024

Connecting Today.
Powering Tomorrow.

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1. Introduction

A reliable system is one that is both adequate and operable, with an operable system having the attributes of flexibility, durability and diversity. To assess these attributes as the electricity system transitions, a number of detailed assessments will need to be conducted; the scope of these assessments will be considered in future Annual Planning Outlooks (APOs). These assessments focus on ensuring that future resource mixes possess sufficient additional services that are essential to ensuring the reliable operation of the system (i.e., essential reliability services). Today, Ontario's power system consists of resources that provide energy and capacity, as well as the essential reliability services needed to support reliable grid operations and respond to the inherent variability and uncertainty of electricity supply and demand.

Figure 1 | Components of Operability

What are **Essential Reliability Services** (ERSs)?

The NERC Essential Reliability Services Task Force defines ERSs as operational attributes that are necessary to reliably operate the power system. Example of ERSs are reactive power to maintain system voltages and physical inertia to maintain system frequency.

ERSs have traditionally been provided by conventional resources such as large nuclear, hydroelectric and fossil-fueled generators. With an evolving resource mix that includes retirements of conventional resources coupled with increasing amounts of variable generation, ensuring a sufficient amount of ERSs is critical to maintaining an adequate level of reliability through the energy transition.

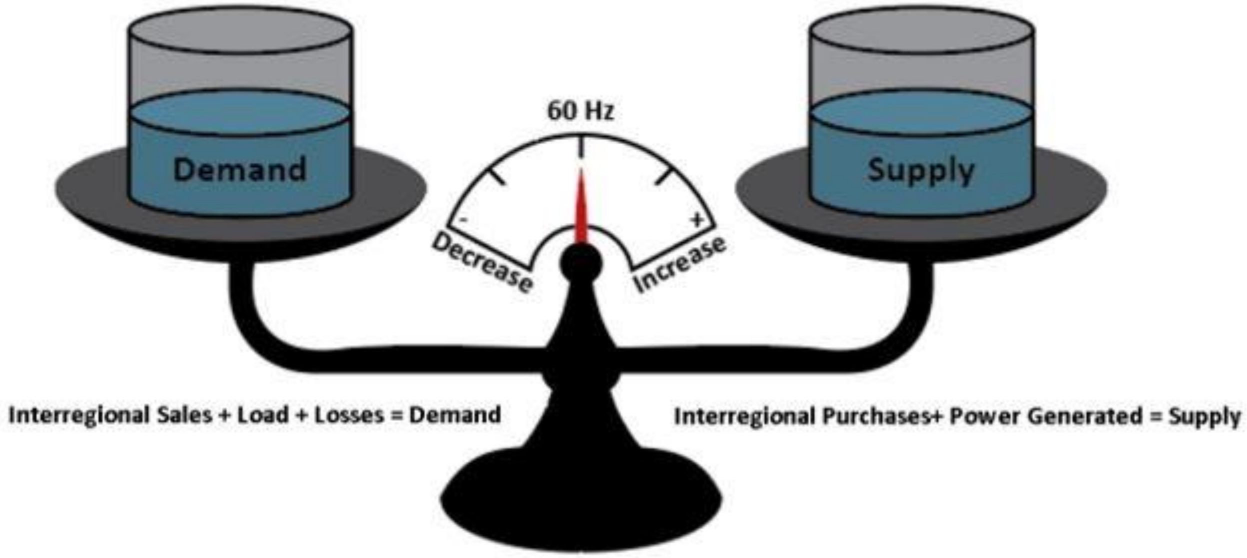
The NERC Essential Reliability Services Task Force indicated that the key attributes of a reliable grid can be categorized into **frequency support** and **voltage support**. This appendix discusses both topics, including an overview of frequency support and the essential reliability services that help ensure that supply and demand are balanced at all times.

2. Frequency Support and Balancing

2.1 What is it?

Rotating electrical equipment on the power system operates at a continuously varying rate (i.e., frequency) of 60 cycles per second, or 60 Hertz (Hz). Frequency will be constant on the system when there is a balance between supply and demand. When supply exceeds demand, frequency increases beyond the scheduled value of 60 Hz until energy balance is achieved. Conversely, when there is a temporary supply deficiency, frequency declines until the balance between supply and demand is restored.

Figure 2 | Frequency Balancing



2.2 Why is it important?

The IESO is required by NERC Reliability Standards to continuously match supply and demand so as to maintain the system in a state of readiness for disturbances that inevitably occur. During normal operations, it is typical for small mismatches between total demand and total supply to occur. Typically, the system is designed to automatically respond to these small mismatches by making continuous adjustments that maintain the delicate balance. However, significant mismatches between supply and demand for a prolonged period of time put the power system at risk of losing generation and/or load, and potentially causing local or widespread blackouts.

2.3 How is frequency support and balancing achieved today?

In real-time operations demand and supply are constantly changing, with resources providing a range of balancing mechanisms to respond to changes as they occur, effectively maintaining system frequency under all conditions. As shown in Table 1, balancing occurs over a continuum of time on the power system (with some overlap in timeframes of occurrence).

Table 1 | Mechanisms of Achieving Balance

Mechanism	Inertial Response	Primary Frequency Response	Regulation	Operating Reserve	Ramping Capability
What is the response time?	Immediately following a system event	Within the first few seconds following a system event	Within minutes of a mismatch between supply and demand	Within 10 minutes or 30 minutes of a system event	Five minutes to hours
How is balancing currently achieved?	Drawn from the stored kinetic energy of rotating equipment	Automatic adjustment of energy output by generators	Signal from IESO tools to a resource to adjust energy output	Activated by the IESO	Scheduled by the IESO’s dispatch scheduling engine

3. Inertial and Primary Frequency Response

3.1 What is it?

Inertial and primary frequency response is an essential reliability service provided by resources that are electrically synchronised to the grid, that is, resources that rotate at the same speed as other resources and are able to quickly respond to conditions that arise on the system.

3.2 Why is it important?

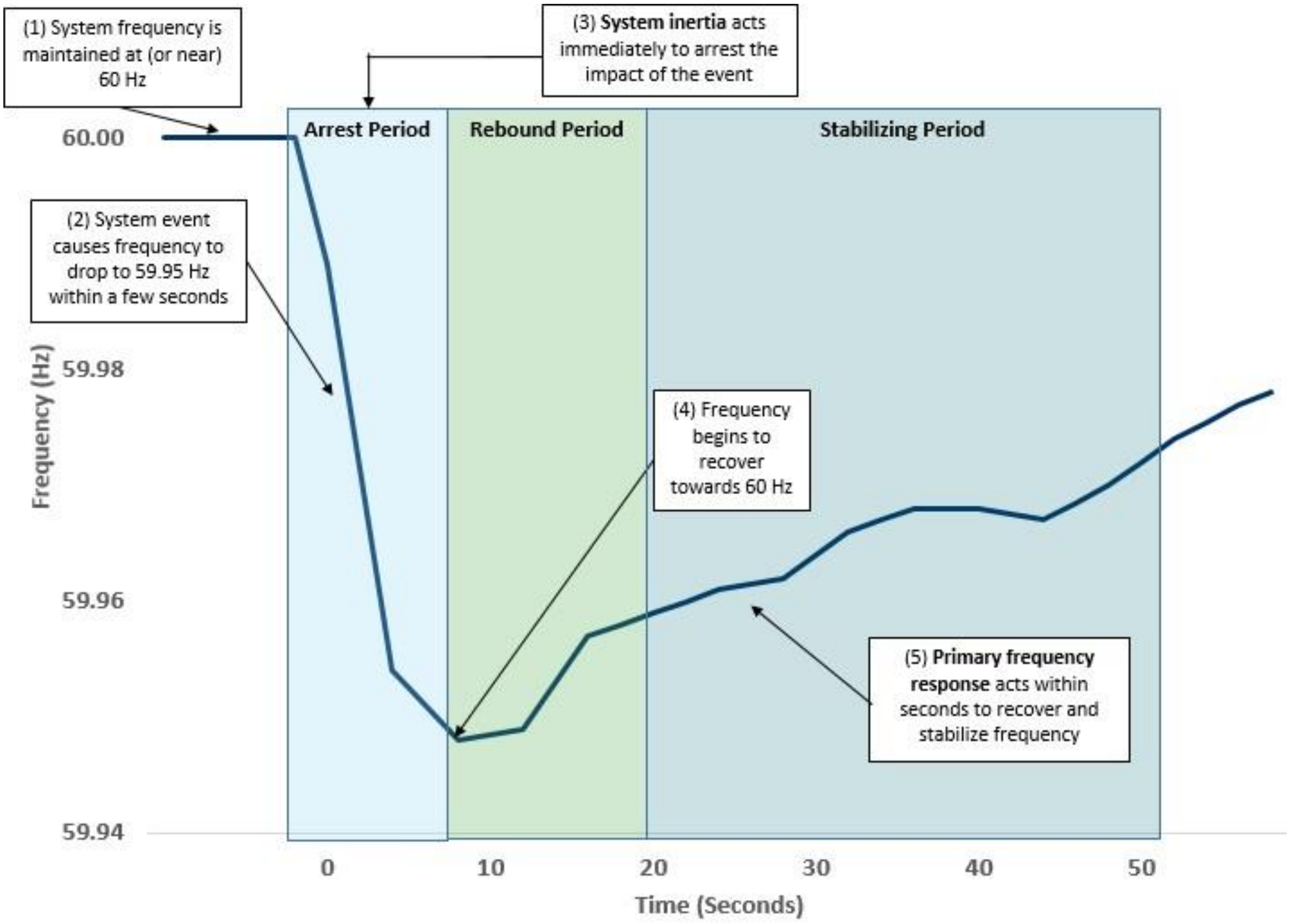
Frequency support is required to restore system frequency to the scheduled value of 60 Hz after an event such as the sudden loss of a large generator that results in an imbalance between load and generation. Such an event initially causes frequency to drop, as stored kinetic/rotational energy is released in an attempt to arrest the electrical imbalance (inertial response), as shown in Figure 3. Arresting further decline in system frequency requires an immediate response from resources connected to the grid. That response slows the rate at which frequency declines by increasing the power output of generators within seconds to stop the fall and stabilize frequency (this is the primary frequency response).

Inertial response and primary frequency response are essential reliability services that are provided by synchronous resources. These resources have large rotating masses that provide inertia to immediately arrest the impact of the event, and governors that sense changes in local system frequency to automatically adjust the energy output of the resource to recover and stabilize system frequency.

Synchronous resources are electrically synchronized to the grid, that is, they rotate at the same speed as other resources and are able to quickly respond to conditions that arise on the system.

Together, inertial response and primary frequency response act to maintain the stability and reliability of Ontario’s power system and the broader Eastern Interconnection, of which Ontario is a part. These reliability services are essential to preventing power system equipment damage, automatic load shedding and ultimately a widespread blackout.

Figure 3 | Frequency Response



3.3 How are these services provided?

Ontario's large hydroelectric and natural-gas fired generators provide both inertial and primary frequency response to maintain balance during system events. Baseload resources (such as nuclear and run-of-river hydroelectric) also provide inertia but are unable to provide primary frequency response, as they typically operate at full output power and therefore cannot adjust energy output to counteract changes in frequency.

Ontario is also strongly connected with the broader Eastern interconnection[1] through interties with New York and Michigan, which can provide supplementary frequency support to Ontario if needed.

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[1] The power system of North America is divided into four main frequency-independent islands - the Eastern Interconnection, Western Interconnection, Texas and Quebec.

Energy sources such as wind and solar, and storage units such as batteries and flywheels, are known as **inverter-based resources (IBRs).** These resources are connected to the grid through electronic inverters, and either have no rotating masses, or the effects of their rotating masses are isolated form the grid by their inverters. As a result, the IBRs do not naturally contribute to the inertial response of the system; however, the control systems of IBRs are increasingly being outfitted with the capability to simulate this type of response.

3.4 What are potential challenges and considerations for the future?

A decarbonized resource mix is anticipated to have an increased number of inverter-based resources and potentially fewer conventional resources connected to the grid. At the same time, higher system demands in the future may increase the amount of frequency response that Ontario is required by NERC Reliability Standards to provide to help maintain the stability of the Eastern Interconnection. As a consequence of these expected changes, recovery from system events may become more challenging in the future, specifically during periods of outages to those remaining resources that provide frequency support.

While existing hydroelectric resources can provide a portion of the frequency support required, other sources of frequency support will also be needed to respond to system events. Inverter-based resources already have some capability to provide primary frequency response and inertia through control systems, but are not currently required to do so in Ontario.

Fast frequency response is an emerging product that can be provided by multiple generator types and demand response, and may replace a portion of traditional frequency support. As technological capability advances, there is potential for frequency support to also be provided by resources such as small modular reactors and natural gas resources retrofitted to use hydrogen as a fuel.

Further technical study will be required to determine the ability of future resource mixes to provide sufficient frequency response during system events, and the minimum amount of synchronous generation capacity that is required on the system to ensure that there is sufficient frequency response as the resource mix is decarbonized.

4. Regulation Service, Operating Reserve and Ramping Capability

Table 2 describes three additional essential reliability services that are required to ensure that balance on the power system is maintained. These are regulation service, operating reserve and ramping capability.

As the resource mix evolves and system needs change as a result of the broader energy transition, ensuring a sufficient amount of regulation service, operating reserve and ramping capability may be challenged. Further considerations that will be required are discussed in this section.

Other resources may be able to satisfy the system's balancing requirements provided they have the demonstrated capability to respond to system needs as described in Table 2. These resources may include storage resources, flexible demand products, and combustion turbines that have been retrofitted to utilize cleaner sources of fuel such as hydrogen. Further assessments will be required as technological capability advances and these types of resources are integrated into the power system.

Table 2 | Reliability Services

Requirement	Regulation Service	Operating Reserve	Ramping Capability
What is it?	Balances normal fluctuations in supply and demand, and helps restore frequency after a system event, and following the primary frequency response	Stand-by power or demand reduction that can be called upon in short notice	The ability to follow changes in Ontario demand
When is it needed?	On a minute-to-minute basis	Following a system event (e.g., loss of a large generator)	Many times a day: on a five-minute basis in real-time and to meet demand forecast for future hours
Why is it important?	Regulation compensates for the normal variations between what is forecast (for demand and variable generation output) and what actually materializes, and is necessary to help maintain system frequency at the scheduled value	Operating reserve helps to restore system frequency to the scheduled value, and maintain reliability following an unexpected event that creates a mismatch between supply and demand	Ramping capability is essential to ensuring that online resources are able to respond to increases or decreases in demand within an hour and in future hours (e.g., during evening pick-up)

Requirement	Regulation Service	Operating Reserve	Ramping Capability
How are needs met today?	Mainly by hydroelectric resources that also provide energy to the system	Mainly by hydroelectric and natural gas-fired resources that are scheduled in the IESO's operating reserve markets	Some hydroelectric resources; natural gas-fired resources (combined-cycle units for longer duration ramps and simple-cycle combustion turbines for shorter duration ramps); and the scheduling of interchange with other jurisdictions

4.1 Regulation Service

An increased penetration of variable generation resources on the system, such as wind and solar, may result in more and/or higher magnitude variations between the forecast and actual output of these resources in the future, putting upward pressure on regulation requirements. In addition, electrification of industrial load processes is expected to further increase regulation requirements. The IESO's assessment of regulation needs is intended to ensure that the system continues to have sufficient resources to respond to the inherent uncertainty that arises with the output of variable generation resources and frequently fluctuating load profiles. The assessment methodology used to determine the regulation needs described in the 2024 APO is described below.

4.1.1 Methodology for Assessing Regulation Needs

Net load is defined as the difference between internal Ontario demand and variable generation output:

$$Net\ Load = Internal\ Ontario\ Demand_t - Wind_t - Solar_t$$

The IESO's regulation service needs assessment evaluates the intra-interval variability of five-minute forecasted values versus one-minute actuals of net load, (i.e., "net load deviations"). Net load deviations are the differences between the five-minute forecasts and one-minute actuals:

$$Net\ Load\ Deviations = Net\ Load_{5-\min forecast} - Net\ Load_{1-\min actual}$$

The IESO's market tools dispatch resources to the five-minute forecasted net load values. However, if the one-minute actuals are higher or lower than the five-minute forecasted values, regulation services must balance the deviations in supply and demand within the five-minute dispatch interval.

For the regulation needs assessment in the 2024 APO, the net load deviations of the five-minute forecasts and one-minute actuals were evaluated; this aligns with the compliance parameters of NERC Reliability Standard BAL-001-2, which are derived from one-minute averages. An illustration of net load deviations is shown in Figure 4.

Figure 4 | Illustration of Net Load Deviations

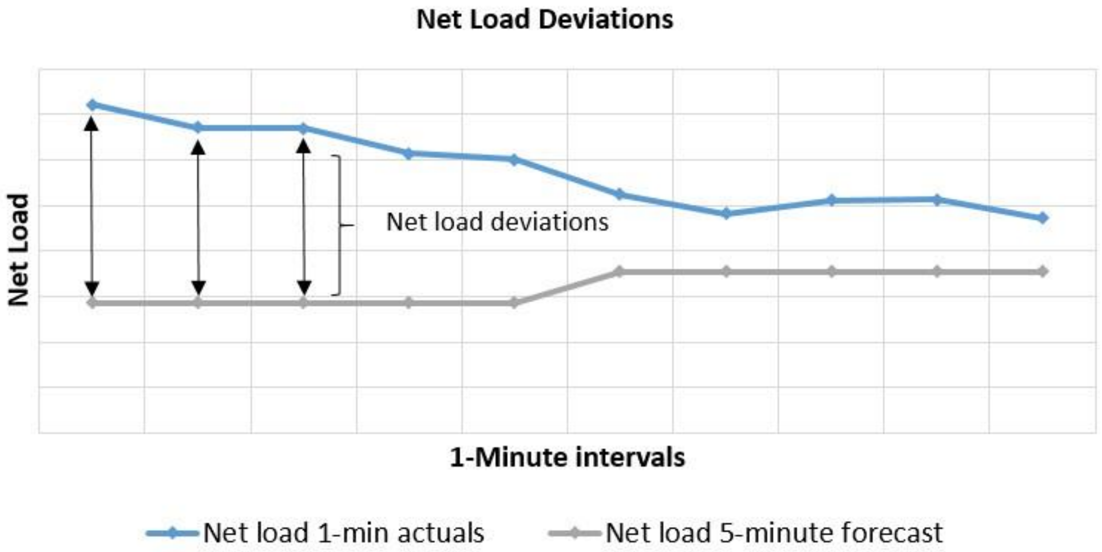
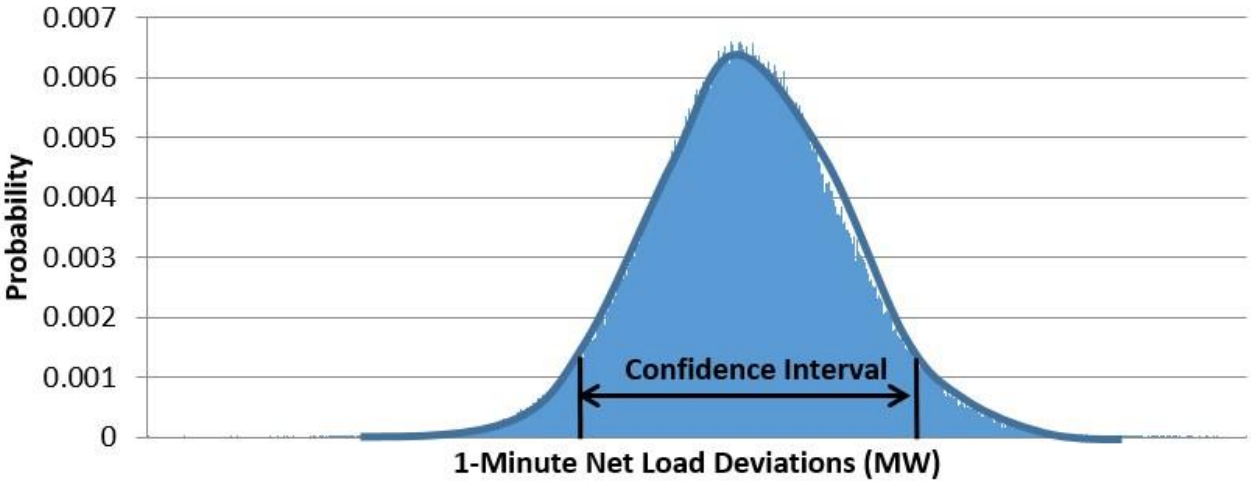


Figure 5 shows the annual one-minute net load deviations plotted on a probability density function. The IESO currently contracts a minimum of ±100 MW of regulation services – this amount has informed the baseline regulation services need, as it historically captured a sufficient amount of net load deviations to maintain compliance to the NERC Reliability Standard BAL-001-2 and meet Market Rule requirements.[2]

Figure 5 | Probability Density Function of One-Minute Net Load Deviations



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[2] Chapter 5, Section 4.4 of the Market Rules requires the IESO to maintain sufficient regulation to meet all applicable reliability standards, and specifies the minimum requirement as ±100 MW.

From the probability density function, a suitable confidence interval that captures a sufficient amount of net load deviations representing the baseline regulation services need can be selected. Once the suitable confidence interval is determined, the required baseline regulation services need can be calculated by taking the mean of the net load deviations and adding a factor of the standard deviation of the net load deviations.

$$Regulation\ Service\ Needs = Mean_{Net\ load\ deviations} \pm Factor(Standard\ Deviation_{Net\ load\ deviations})$$

To assess the impact of the expected addition of industrial loads with highly fluctuating operating profiles, the net load five-minute forecasts and net load one-minute actuals were appropriately adjusted using the synthetic one-minute load profiles as provided by the industrial load market participants.

To assess the impact of load growth, the net load five-minute forecasts and net load one-minute actuals were appropriately adjusted using the load growth forecasts presented in the 2024 APO. To avoid double-counting, the load growth forecasts were reduced by the load profiles of additional industrial loads.

The assessed cases include all of the currently known industrial loads with highly fluctuating operating profiles and their expected commercial operation dates, and the annual load growth forecasts. By assessing the impact to net load deviations using the selected confidence interval for load growth and the expected addition of industrial loads, regulation service needs can be determined for each of the assessed cases. The difference between the regulation service needs of each of the assessed cases and the baseline regulation service needs expresses the incremental regulation service needs above the current ±100 MW requirement.

Future regulation needs may change based on updates to the demand forecast, changes to the in-service dates or size of the expected industrial loads, or increased penetration of variable generation resources. The IESO will continue to assess needs that incorporate these and other dynamic factors and will adjust future regulation needs accordingly.

4.2 Operating Reserve

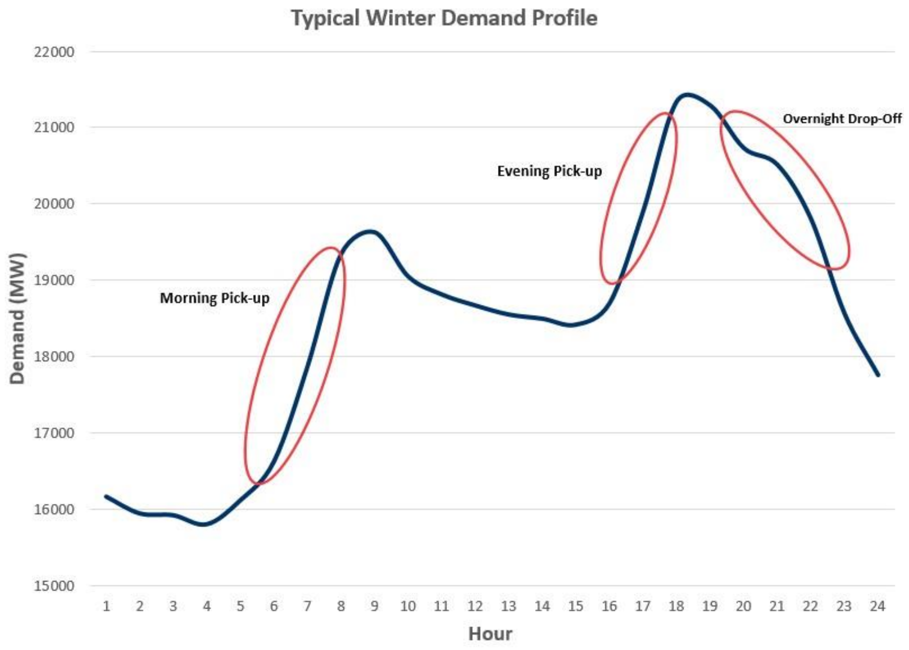
Meeting operating reserve requirements today is already a challenge during certain periods of the year, such as the spring or fall seasons when demand is typically lower and very few natural gas-fired resources are online and providing energy. This is further exacerbated when these periods coincide with periods of freshet and the hydroelectric resources are utilized to maximize energy production and are not available to provide operating reserve to help respond to system events.

With natural gas resources providing a significant amount of Ontario's operating reserve requirements today, a decarbonized resource mix will need resources that can help meet provincial operating reserve requirements at all times of the year and under various system conditions. For example, battery storage resources are anticipated to play a role in providing operating reserve in the future. However, their limited energy capability will mean that once activated to produce energy, they will be available for a finite amount of time after which they will need to be recharged. Replenishing battery charge will impose additional load on the system, which may not be feasible during periods of high demand (such as on peak summer or winter days) or days when output from variable generation resources is low.

4.3 Ramping Capability

As other sectors of the economy decarbonize to meet broader emissions targets, and reliance on the electricity system grows, a change in today's demand profiles is anticipated (the demand profile from a typical winter day is shown in Figure 6). This may create an additional need for system ramping capability as periods of load pick-up and drop-off occur more often and/or become steeper during the day. In addition, steeper changes in load pick-up could be exacerbated by an increased number of solar resources on the distribution system, particularly over the evening period; as the output of these resources decreases, this will have the effect of adding to system demand.

Figure 6 | Ramping



With natural gas resources meeting a significant amount of system ramping needs today, a decarbonized resource mix may be increasingly challenged to meet daily ramps in demand as they occur in real-time or are anticipated to occur in future hours. This can also be further exacerbated during periods of freshet when hydroelectric resources are unavailable to provide ramping capability.

5. Reactive Support and Voltage Control

5.1 What is it?

Reactive support and voltage control service is required to maintain acceptable reactive power and voltage levels on the power system.

5.2 Why is it important?

Acceptable voltage levels are required to move power through the transmission and distribution system from generators to end consumers. Maintaining adequate voltage profiles across the power system is critical to reliably operating the system, both during normal operations and following a system event. Power sags (dips) and prolonged low-voltage events can affect large areas and create more widespread events, while high-voltage events can result in equipment damage and potentially the loss of life.

5.3 How are reactive support and voltage control needs met today?

All generating resources injecting energy into the system are required to provide a certain level of reactive support and voltage control service in accordance with the Market Rules. The IESO also contracts some resources to provide additional amounts of this service in order to meet system needs.

5.4 What are potential challenges and considerations for the future?

Synchronous resources provide the system with a significant amount of reactive power and voltage control today, which may be challenged in the future by a resource mix with a decreased proportion of synchronous resources. Considerations to ensure a system with a sufficient amount of reactive support and voltage control may include:

- Enhancing the capability of conventional power electronic inverter-based resources to exhibit similar characteristics as synchronous resources, and
- Integrating technologies such as synchronous compensators (rotating machines that contribute to reactive power and voltage control but do not produce power) on the power system.

6. Additional Considerations

In addition to the essential reliability services discussed above, other areas of study will be required as the resource mix evolves to ensure reliable operation of the power system.

6.1 Black Start Capability

Black start capability is critical to restoring the power system in a timely manner following a power system blackout. This service is provided through certified black start resources that have the ability to start without drawing power from the grid or other sources of generation. Once started, these resources can in turn support the energization of transmission elements, other generation units and load in a defined area of Ontario.

Today, hydroelectric and natural gas resources provide black start capability in Ontario. In-depth analysis will be required as the resource mix evolves to ensure that the system has sufficient black start capability; this will include a transmission analysis that incorporates the location of black start resources. As technologies advance, other types of resources may also be able to provide this service in the future.

6.2 Ability to Manage Resources

Significant effort will be required to maintain reliability of the power system during the energy transition. Another system attribute and key focus area for the IESO is manageability, which is a critical aspect of reliable operations. Manageability is the attribute that enables the IESO to have visibility of, monitor and direct the operation of the majority of resources across the system.

The 2023 Electric Reliability Organization Reliability Risk Priorities Report indicated that the power system is becoming more complex as a result of the energy transition, with the need to model, analyze and operate the system at higher fidelity. This can increase the risk to reliability posed by human error as training, staffing and workforce issues increase to support grid transformation and decarbonization. To manage this risk, updates will be required to the IESO's internal models, tools and processes to effectively integrate and operate new resource types and technologies. Changes may also be required to current planning, operating and market approaches to optimize existing resources and enable new resources to support the transition.

6.3 Seasonal and Extreme Event Analysis

Seasonal weather changes and extreme events such as a heat wave or cold snap can impact power system equipment and the performance of resources. For example, extreme heat conditions typically result in higher forced outages on the system, as well as low water conditions that can reduce hydroelectric output and impact the ability of these resources to provide energy and operating reserve. In-depth analysis will be required to ensure that the electricity system is resilient through a variety of conditions, and that the resource mix possesses the characteristics necessary to withstand these conditions. In addition, a changing climate that results in more periods of drought may not only limit the ability of hydroelectric resources to provide operating reserve, but also energy.

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