WECC

White Paper

Energy Storage Services

Energy Storage Task Force

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Executive Summary

The purpose of the Energy Storage Services paper is to identify service products that are essential to or enhance the reliably of the Bulk Power System (BPS). The paper has divided these services into three groups based on their specific role in power system operation. The paper focuses on energy service products, transmission service products, and ancillary service products. The paper describes characteristics of energy storage and the benefits storage can provide.

This document will define the various products/services, explain how storage provides these services, and compare conventional generating resources to storage resources.

By introducing more flexibility into the grid, energy storage can help integrate more solar, wind, and distributed energy resources (DER). Energy storage can reduce ramping and cycling of thermal units and improve the reliability and dynamic stability of the power system by providing stable, abundant energy reserves that require little ramp time.

As renewable portfolio standards (RPS) and goals for states and provinces within the Western Interconnection become commonplace, storage resources will play an increasingly important role as fewer fossil fuel resources are available to provide reliability services and support efforts to meet zero-carbon emission resource goals.

Storage is a unique asset that can provide both generator and transmission services. Energy storage is an effective and efficient method to mitigate transmission congestion and defer transmission and distribution projects.

This paper discusses the value and challenges of energy storage when associated with microgrids. Microgrids are self-contained electric grids consisting of distributed generation sources, storage, and load that can operate as an "island" independent of the central power grid.

The paper discusses ancillary services that are necessary to support the transmission of electric power from generators to consumers. These services consist of frequency control, voltage control, load following, ramping, contingency reserves, and blackstart capability. NERC has identified frequency response, balancing, and voltage control as Essential Reliability Services. Energy storage can provide a wide range of ancillary services often equal to or better than conventional generators.

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1 Introduction—Energy Storage Service Products

This paper identifies service products that are essential to or enhance the reliability of the bulk power system. These services are divided into three groups based on their specific role in power system operation: energy service products, transmission service products, and ancillary service products. The paper describes characteristics of energy storage and the benefits storage can provide. This document will define the various products/services, explain how storage provides these services, and compare conventional generating resources to storage resources.

1.1 Service Products

Energy storage offers benefits in three main categories. Energy service products are versatile and can provide energy as needed to continuously meet changing demand and resource variability. Transmission service products can defer transmission expansion and provide congestion relief. Ancillary service products maintain proper power flow while addressing imbalances between supply and demand. These services can include frequency response, balancing, and voltage control.

1.2 Characteristics of Energy Storage

1.2.1 State of Charge Visibility and Management

Unlike gas and coal resources that are generally capable of high-capacity factors, energy storage systems typically have finite megawatt-hours of energy without being recharged. This is similar to a hydroelectric resource that has pondage or flow limitations over a given period. Storage resources can be an energy resource (and at times a load) and, as described later, provide not only energy but a multitude of ancillary and transmission services. To reliably use storage to its full potential, system planners and operators must ensure that storage resources are charged to the level needed to supply the intended services. This value is known as state of charge (SOC) and is typically expressed as a percentage of the storage megawatt-hour capability or as the megawatt-hours of energy contained in the storage device. It is vital that system operators always have clear knowledge of the current SOC of the resource. As operation of the storage system can cause it to charge and discharge throughout the day, system resource plans and real-time operations must ensure there is adequate SOC for the upcoming planned usage.

1.2.2 Ramping Capability

As storage resources can ramp very quickly, managing the ramp rates may be necessary. Ramp rates may need to be reduced to less than their maximum capability for energy and ancillary service products.

When providing energy, the resource is expected to ramp symmetrically between two dispatch points, usually at a less-than-the maximum rate. If many resources ramp non-symmetrically, Balancing Authorities' (BA) Area Control Error (ACE) can be affected.

Inverter-based energy storage resources responding to Automatic Generation Control (AGC) have been known to cause real-time operational challenges when allowed to ramp at their highest rate. These challenges include excessive use of up/down regulation, fluctuations in high/low ACE, and an increased tendency to lean on the interconnection. It has been demonstrated that AGC-induced oscillations can be dampened when AGC ramp rates are reduced. The NERC Inverter Resource Performance Subcommittee (IRPS) developed a **Reliability Guideline**, BPS-Connected Inverter-Based Resource Performance that provides information on the importance of control system interaction of inverter-based resources (IBR) and traditional resources need to be coordinated.

1.2.3 Hybrid Resource Considerations

Increasingly, renewable energy resources (especially solar) and storage are being constructed in proximity to each other and share a Point of Interconnection (POI). These combined facilities are generally described as hybrid when they are treated as a single power plant or co-located when the renewable and storage facilities are dispatched as two separate plants behind the common POI. Energy from the renewable resource can be directly delivered to the grid or stored for later use. A benefit of these hybrid or co-located facilities is an increased use of the associated transmission since energy can be delivered to the grid for extended hours. Regardless of whether the plant is dispatched as a hybrid or co-located plant, the plant construction, including metering and controls, will be essentially the same.

1.2.4 Charge Management

Certain storage technologies have operating characteristics that may be dictated by equipment limitations or contractual agreements. Among these are duration of charge, average SOC limitations, and cycling limitations. All storage technologies have a limitation on the megawatt-hours of energy they can store and therefore there are limits on the duration of discharge when operating at high output. Long duration storage technologies are in various stages of development. Although definitions vary, it is commonly assumed that long-duration storage may provide discharge at full output for 8-10 hours. Technologies like pump storage hydro can hold thousands of megawatt-hours. The megawatt-hour ratings are an important component in determining the value of the resource. In addition, some technologies have limits on the average SOC over some specified period and limits on the number of charge/discharge cycles of a given period.

1.2.5 Operation During Adverse Weather

Certain storage technologies, particularly wind and solar, are heavily influenced by weather conditions. Heavy cloud cover or lack of wind, particularly over many hours, will lead to reduced energy generation. This may require the grid operator to choose between real-time delivery to the grid and providing charging energy to the storage resource. As discussed in the State of Charge Visibility and Management section, both planners and operators will have to use weather forecasting in developing their energy portfolio.

1.2.6 Frequency Response from Storage Resources

Historically, primary frequency response in power systems was provided by system inertia—the energy stored in large rotating generators and some industrial motors. Resources providing inertia are decreasing with the increasing deployment of wind, solar, and inverter-based storage, and the resulting retirement of fossil-fuel generation facilities. Many studies are being performed to see how system reliability can be maintained as rotating mass resources are decommissioned and what role storage resources play in this evolving grid. The Changes in System Inertia Advisory Group produced a **report**, Changes in System Inertia that was published in 2021. Storage using conventional synchronous generators, such as pump-storage hydro, will continue to provide frequency response from inertia. Inverter-based storage can also provide frequency response by quickly detecting frequency deviations and respond to system imbalances. Tapping into electronic-based resources for this "fast frequency response" can enable response rates much faster than traditional mechanical response from conventional generators. Replacing conventional generators with IBRs, including wind and solar, coupled with co-located or standalone storage, has two counterbalancing effects. First, loss of the conventional resources decreases the amount of inertia available. But second, these resources can provide the frequency response needed, thus addressing the first effect. This represents a shift in how we think about providing frequency response.

1.2.7 Inverter-Based Controls Considerations

The design and programming of the inverter-based controls, used in many energy storage systems, is a key element in a reliable system design. There have been issues identified with inverter-based resources in several disturbance reports. One main issue is various inverter protections operating based on settings lower than needed to protect the equipment. The Loss of Solar Resources during Transmission Disturbances due to Inverter Settings NERC Alert II distributed May 1, 2018, specified that protections operate only at levels necessary to protect equipment. Another issue is momentary cessation where the inverters will discontinue power injection during a fault. Part of the problem was found to be misapplication of PRC-024 requirements. The NERC Alert has specified that momentary cessation should be blocked if possible. If not, the initiating threshold should be set as wide as possible, recovery time should be set to the minimum possible and the recovery ramp rate should not be impeded by plant controls.

1.3 Benefits of Storage

1.3.1 Improve Dynamic Stability

Many energy storage technologies employ power electronics, so their controls and capabilities can be designed to improve system operation under disturbance conditions. These controls can be set to inject real or reactive power depending on the needs identified by the Transmission Operator in the interconnection agreement. This capability is enhanced through the use of modern grid-forming inverters, inverters having a control approach with the capability to control the terminal voltage directly and to form the grid voltage purely by the inverters. Energy storage can improve the reliability and dynamic stability of the power system by providing stable, abundant energy reserves that require little ramp time as well as critical voltage support.

1.3.2 Reduced Cycling and Ramping of Thermal Units

Starting and ramping of thermal units creates added stress on the unit, increasing maintenance costs and outage time. Starting and ramping also negatively affects heat rate and increases hazardous emissions. Energy storage can ramp up quickly to help balance generation and load and smooth the output of VERs. This can reduce inefficient ramping of thermal units and starting and stopping of conventional generators.

1.3.3 Reduced Environmental Emissions

Energy storage can have positive impacts on air quality; among these are reductions in NOx and greenhouse gas emissions. By introducing more flexibility to the grid, energy storage can help integrate more solar, wind, and DERs. It can also improve grid efficiency—increasing the capacity factor of existing resources—and offset the need to build new pollution-emitting power plants. As our energy supply mix gets cleaner with the addition of low- and no-carbon resources, energy storage helps that supply mix evolve more efficiently and reliably.

Thermal units tend to emit excessive pollutants during start-ups and shutdowns when their environmental controls cannot operate efficiently or at all. These units are also more efficient, and therefore, cleaner, at a steady load. By adding energy storage capacity to the grid, the need for new polluting resources is reduced, and eventually, eliminated.

Energy storage can be charged from excess renewable energy at certain times of the day. This stored energy can then be delivered to the grid at other times, as needed, reducing or eliminating the need to start thermal peaking units. It can also be used for load following and to smooth the intermittency of variable energy resources (VER). This reduces the need to ramp thermal units.

It should be noted that, except for certain hybrid and co-located applications, we cannot determine the specific resource being used to charge storage when the energy is coming from the grid. Thus, some charging may be from gas-fired generation. However, there is still benefit to the system because this charging energy can come from cleaner, more efficient thermal resources rather than starting and operating less efficient peaking units.

The environmental benefits of energy storage will increase over time as the grid becomes greener and more stored energy comes from renewables. Long duration energy storage will also play a significant role in adding to the environmental benefits by increasing the ability to move excess renewable energy beyond daily shifting to weekly and, ultimately, seasonal periods.

1.3.4 Energy Security

Energy storage provides energy during times of the day when wind and solar generation are not available to deliver energy to the grid. This bolsters the energy portfolio and minimizes reliance on fossil fuels.

2 Energy Service Products

Traditional resources provide valuable energy services. Independent System Operators (ISO) and BAs can use the capabilities of energy storage to perform these necessary services to ensure reliable and stable electrical grid operations. This section explains how energy storage accomplishes these services, compares how existing resources provide these services, and compares the ability of energy storage resources to perform these services.

2.1 Load Leveling

The BAs are responsible for serving load throughout all hours of the day. During many hours, the most efficient and least-cost generation comes from renewable resources, including wind and solar generation. The BA forecasts an output from these resources and subtracts it from the system load to determine the net load. The BA then dispatches its remaining resources to meet this net load.

Resources that provide load-leveling store energy when net load is low and discharge energy when net load is high. This process smooths or levels net loads. Load leveling typically occurs during morning and evening load ramps and midday during high renewable output. Another use would be during times of variable cloud cover that affect solar output on grid and rooftop solar. The same can be said when wind generating output is affected by wind variation.

Figure 1 is an example of the typical pattern of the aggregate energy charge (values below the x-axis) and discharge (values above the x-axis) from the battery storage fleet within the California

Independent System Operator (CAISO) BA footprint.[1] Figure 2 shows the demand and net demand for the same day.[2] These charts demonstrate the load-leveling capability of battery storage.

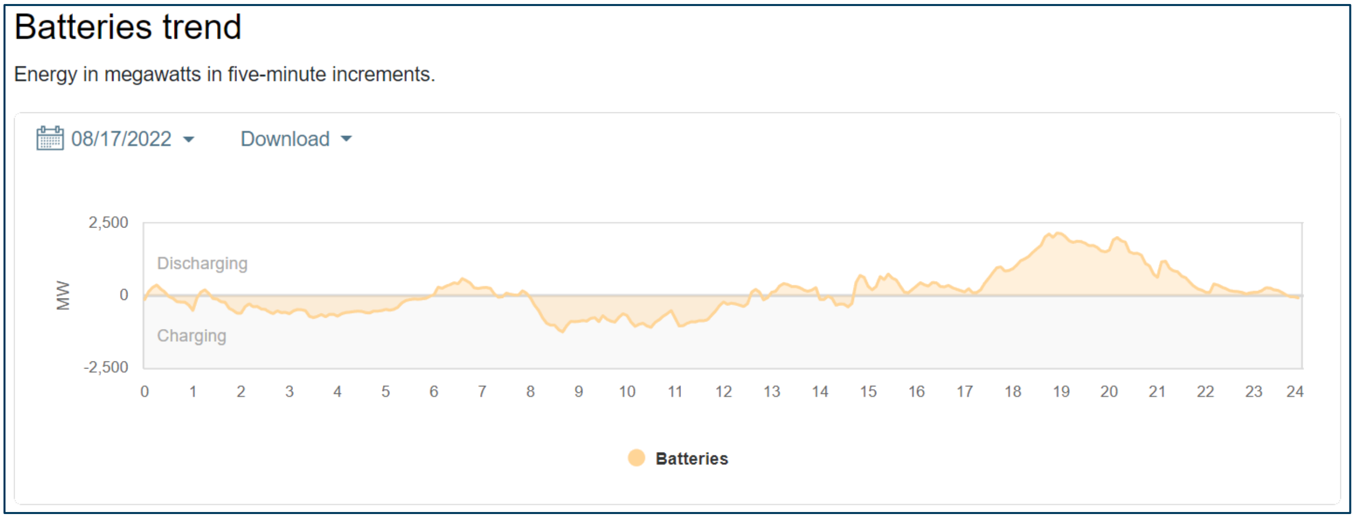

Figure 1: Aggregate energy charge and discharge from battery storage fleet in CAISO footprint.

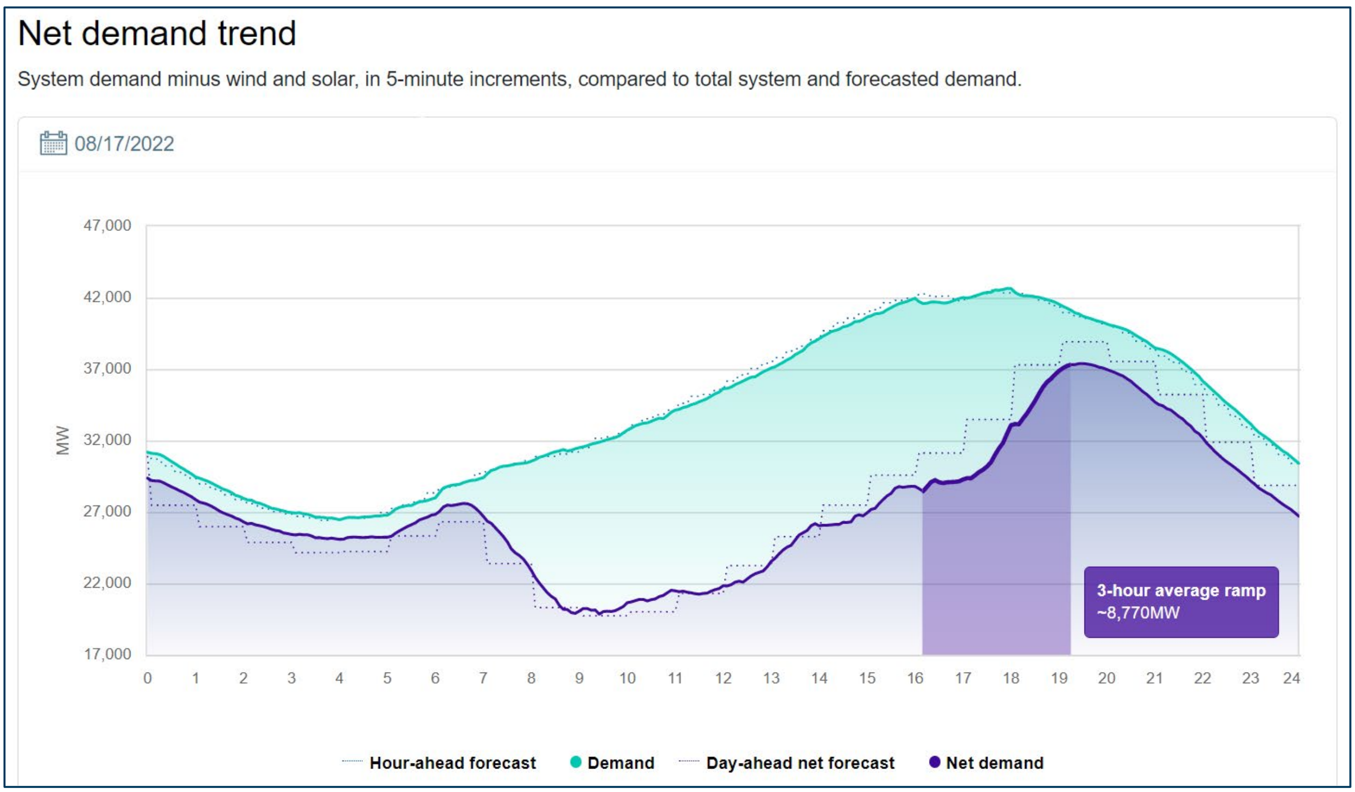

Figure 2: Demand and net demand for August 17, 2022.

[1] Source: http://www.caiso.com/TodaysOutlook/Pages/supply.html

[2] Source: http://www.caiso.com/TodaysOutlook/Pages/index.html#section-net-demand-trend

2.2 Time Shifting

Time shift involves charging energy storage resources during periods when there is excess supply so that the stored energy can be discharged later during periods of high demand and reduced supply. There are periods in the day when energy supply exceeds demand and when energy demand can exceed the supply of system generation. Storing energy during periods of excess supply, so the energy is available during periods of high demand or low intermittent resource availability, is a valuable capability of energy storage systems.

2.3 Generating Capacity

Energy storage can provide energy as needed to meet demand similar to conventional generation. Charge limitations (megawatt-hours) of energy storage may preclude the use for extended periods. Energy storage used as a base-load unit is currently not optimal, as most energy storage resources are designed for a four-hour duration. However, there are emerging technologies capable of longer duration, which will change the way energy storage is operated.

2.4 Observations and Gap Analysis

Energy storage is becoming a significant resource in the energy supply portfolio. These storage resources, when properly managed, can effectively supply required energy. Table 1 compares and contrasts the ability of energy storage to supply needed energy with conventional generating resources

Table 1: Energy storage ability to supply energy versus conventional generating resources' ability

Comparison Topic	Traditional Solution	Storage Solution
Load Leveling	Pump storage stores energy when load is low and gives energy when load is high. Studies indicate that construction of new pump storage facilities will be limited in the Western Interconnection. High initial capital costs, environmental approval processes, limited geographic locations, and lengthy time for commercial operations are factors.	Energy storage resources are extremely versatile for these purposes compared to the pump storage model. Shifting from charge to discharge quickly adds value to using energy storage. Characteristics of energy storage must be considered; batteries have limited capacity, limited rate of charging, and resources may not be dispatchable at 100% of their nameplate rating. Some hold back 5–10%, based on their manufacturers' recommended specifications.
Energy Arbitrage	Pump Storage can be used as an arbitrage resource but is limited by the transition constraints when	An energy storage solution is more seamless by operating across charge/discharge without transitions

	switching between generation and pump modes. This can be mitigated through the use of variable speed pump-turbines that are not yet common-place in the Western Interconnection.	or "full on/full off" … similar to variable speed pumping. Energy storage can charge when prices are low and return energy to the grid when prices are high.
Time Shifting	Typical time shifting for pump storage resources occurs in a diurnal pattern, depending on load patterns and renewable resource output.	Storage is ideally suited to time shifting due to its ability to charge when desired and discharge as needed. Certain characteristics of energy storage must be considered—batteries have limited capacity, limited rate of charging, and are not 100% efficient.
Generating Capacity	Generating capacity is provided by dispatchable thermal and hydro resources. The amount that is available depends upon nameplate capacity and fuel supply (i.e., coal, gas, water). As state and provincial RPS goals become commonplace, fewer fossil-fuel resources will be available to provide these services.	Energy storage provides system capacity when needed by storing excess energy from other periods. This capacity can be used to provide energy or held back to supply system reserves. This capacity can be rapidly delivered, as many storage types are always synchronized to the system and ready to absorb or supply energy. Consideration must be given to the amount of energy actually stored and the planned future need.

3 Transmission Service Products

Storage on the transmission system can improve both reliability services and efficiencies of the grid by injecting or absorbing power to provide congestion relief, decrease unserved load, and reduce renewable energy curtailment. Storage is a valuable asset that can provide generator and transmission services. Development of energy storage can generally be completed more quickly than transmission, considering the various aspects such as siting, easement and permits, procurement, and installation of equipment. The cost of storage can be the least-cost reliability solution for Transmission Operators and a market solution for Regional Transmission Organizations (RTO) and ISOs. It will be an even more effective solution if the duration of storage increases from four hours to a considerably longer period.

3.1 Transmission Deferral and Congestion Relief

Congestion relief is a process that allows Reliability Coordinators (RC) and Transmission Operators (TOP) to mitigate potential or actual operating security limit violations while respecting transmission service reservation priorities.

Energy storage is an effective and efficient method of deferring transmission and distribution (T&D) projects. Strategically located energy storage projects can be very effective in keeping the loading of the T&D system equipment below system ratings. Non-wires alternatives (NWA) are those projects where DERs, including storage and microgrids, are used as generation to provide the least-cost alternative for capital investments. Another term that is commonly used is "storage as transmission asset (SATA), where a utility-scale storage project can defer capital transmission investments. FERC Order 841 requires that energy storage be considered as an alternative to transmission additions.

The traditional way to relieve congestion was by building transmission lines to increase the capacity to support the additional power flows to serve the load with the least-cost generation. But storage technologies and renewable generation are changing traditional planning processes.

Energy storage can act as a generation asset as well as a transmission asset in the system planning process. These fast-responding resources can be key in helping to mitigate the reliability impacts and support operations. Using storage for both generation and transmission is called dual-use storage. These dual-use storage benefits depend on location, energy market structure, generation mix, rates, and T&D infrastructure.[3]

A combination of storage and transmission can be an effective solution for inter-regional coordination considering weather and operational conditions. For example, to manage congestion, storage can be located at optimal locations near the load centers or renewable generation. The flexibility of storage enables it to switch between charging and discharging instantaneously based on the grid's needs. Dual-use storage assets are uniquely capable of providing transmission congestion relief and ancillary services.

- In ISOs and RTOs, dual-use storage is controlled by the ISO or RTO when providing transmission relief and by the Generator Owner (market participant) during market participation. This participation model raises competing priorities between reliability and market participation. As grid operators are subjected to mandatory reliability standards, it is imperative that dual-use storage prioritize the reliability function over market participation. This introduces uncertainty for operations and can expose dual-use storage to penalties.

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[3] Energy Storage for a Modern Electric Grid: Technology Trends and State Policy Options; by Glen Andersen, Laura Shields, NCSL Jeremy Twitchell, Pacific Northwest National Laboratory, National Conference of State Legislatures 2020.

Storage can effectively improve the reliability of the grid with least-cost capital investments. Allowing the storage to provide reliability services for operational need, then allowing it to participate in markets with appropriate cost recovery structure, is beneficial to the customers.

3.2 Micro Grids (Islanding)

Microgrids are self-contained electric grids consisting of distributed generation sources, storage, and load that can operate as an "island," independent of the central power grid.[4] A combination of renewable generation and storage can serve load for several hours independently when decoupled from the utility.

Microgrids are small portions of the power system that can operate in islanded and grid-connected modes to meet the growing power demand due to electrification, or the retirement of fossil generation, and to manage climate change. They are a promising solution for providing power to commercial and industrial customers such as hospitals, military bases, universities, mines, etc. under adverse conditions. The microgrid's advantage is that it can provide uninterruptible power during contingencies, including severe weather conditions. The generating resources of the microgrids are intermittent renewable resources and small combustion or diesel generators to balance the dynamic load. The intermittent nature of the generation combined with load forecast changes poses operational challenges. Storage acts as an energy buffer[5] to address the mismatch of the power demand and generation, improving the reliability and stability of the microgrid. Storage manages the bi-directional power flow, reducing the operating losses and providing the inertia needed to stabilize the islanded network.

Storage plays a critical role in microgrids by enhancing the system stability, power quality, and reliability. The major difference between traditional generation and microgrids with inverter-based generation is the time of response and inertia. For storage to effectively support voltage and frequency, it is imperative to install proper type, size, and location of energy storage within a microgrid. Storage can improve power quality by mitigating intermittency of renewable generation, harmonic compensation, power factor correction, and voltage support.

- Storage is a source of active and reactive power-controlling power flow changes due to renewable energy and load. Energy storage improves reliability by allowing an islanded section of the grid to continue operation until normal operation is restored.

[4] https://environmentamerica.org/energy-101/microgrids-energy-storage

[5] Nazaripouya, Hamidreza & Chung, Yu-Wei & Akhil, Abbas. (2019). Energy storage in microgrids: challenges, applications, and research need. International Journal of Energy and Smart Grid. 3. 60-70. 10.23884/IJESG.2018.3.2.02.

Storage is a critical asset in the microgrids and effectively provides reliability, power quality, and stability. Three main challenges should be addressed for effective implementation of storage in microgrids: cost, duration of operation, and appropriate development of design specifications. These should be addressed for the proliferation of reliable microgrids that can support remote customers.

3.3 Observations and Gap Analysis

Storage is a dependable technology that enhances reliability in normal interconnected operation and microgrids. It is also an effective resource to eliminate or defer the need for T&D upgrades. There are challenges to using dual-use storage as both generator and transmission assets as the markets designed were for traditional resources. Table 2 compares the traditional and dual-use storage solutions to better understand the differences and the gaps that should be addressed.

Table 2: Traditional versus dual-use storage solutions

Comparison Topic	Traditional Solution	Storage Solution
Congestion relief	Transmission development.	Addition of storage in an optimal location to mitigate congestion.
Years of development	Transmission solutions take 10 years or more for deployment from the time congestion is identified.	Storage depends on the interconnection queue and can be deployed in a much shorter time based on siting and generation interconnection.
Scalability	Transmission line upgrades or construction is in large increments, which can be beyond the needed increase. The flexibility to scale the transmission lines according to need is difficult.	Storage can be scaled to the need for congestion relief and the capacity can be increased by adding storage.
Interconnection policy	Transmission solution is typically part of transmission plans. Simple reinforcements such as upgrades or adding equipment in substations can be completed in one to two years based on the need.	Storage should go through the interconnection process which can take longer for clogged queues. It might be more than two years for the large-scale utility solar deployment.
Duration of relief	A transmission solution can relieve congestion without any time limit. Once built, the loading relief can occur at any time.	Current storage duration is typically about four hours at rated discharge beyond which the congestion cannot be relieved. The need for long-duration storage that

		can support long-duration relief is a gap with current deployment.
Market compensation	Transmission activities do not distort market prices and are strictly developed for relieving congestion and reliability improvement.	Storage which can act as both generation and transmission can suppress market prices. The current markets are not designed to handle such assets.

4 Ancillary Services Products

Ancillary services are necessary to support the transmission of electric power from generators to consumers. Ancillary services maintain the proper flow of electricity, address imbalances between supply and demand, provide adequate voltage regulation, and help the system recover after a power system event. Among these services, NERC has identified frequency response, balancing, and voltage control as Essential Reliability Services. BAs and transmission utilities within those BA areas are required to provide or procure these services to maintain reliable operation of the interconnected transmission system.

4.1 Frequency Control

Each BA is required to provide or procure resources or equipment capable of responding to and correcting changes in system frequency. These resources must be able to assist the interconnection in maintaining Scheduled Frequency. This assistance can include turbine governor response, IBR electronic controls, and AGC. Per NERC Standard BAL-003-1, each BA must provide sufficient Frequency Response to maintain Interconnection Frequency within predefined bounds by arresting frequency deviations and supporting frequency until the frequency is restored to its scheduled value.

In conventional-type generators, frequency control is normally provided by action of a generator governor. Many storage technologies are IBRs and rely on the action of fast-acting digital control systems. The response magnitude is determined by a droop setting that responds proportionally to the frequency deviation. Storage resources can supply the required frequency response in all time frames described below.

Steady-state frequency control is the ability of generating resources to respond to small changes in frequency by continuously increasing or decreasing the generator output when frequency deviates outside a specified dead band.

Primary Frequency Response (PFR) is the first stage of frequency control and is the inherent response of resources and load to arrest local changes in frequency. PFR is automatic, is not driven by any centralized system, and begins within seconds after the frequency changes. The magnitude of response should be proportional to the frequency deviation and is determined by a governor droop setting.

Secondary Frequency Responses (SFR) are the actions taken to correct the resource-to-load imbalance that created the original frequency deviation. It comes from either manual or automated dispatch from a centralized control system or by operator action. It restores the system to the scheduled frequency and restores the PFR capability. SFR should be completed during the disturbance recovery—15 minutes after a disturbance.

4.2 Regulating Reserve

Regulating Reserve is an amount of generating reserve, responsive to AGC, used to control a BAA's ACE. System regulation is an ancillary service for which storage is well suited. Regulation involves managing system resources to balance actual interchange flows with other control areas to closely match the scheduled interchange. The primary reason for regulating the power system is to maintain the grid frequency. The rapid-response characteristic of most storage systems makes it valuable as a regulation resource.

Battery energy storage systems (BESS) can rapidly charge or discharge in a fraction of a second, faster than conventional thermal plants, making them a suitable resource for short-term reliability services, such as PFR and Frequency Regulation.

4.3 Flexibility Reserve

Flexibility reserve is an additional reserve carried by a system to meet the variability and uncertainty introduced by VERs. Storage can be a valuable resource in this area in two ways. First, storage coupled with a VER can be used to control the combined output of a facility to a level at or near the target output thereby reducing the need to carry additional reserves. Second, storage can directly supply the needed flexibility reserve on a properly designed and operated system.

4.4 Contingency Reserves

Contingency Reserve is an amount of additional capacity, beyond what is directly serving load, that may be deployed by the BA to respond to a Balancing Contingency Event and other contingency requirements. Contingency Reserves must be capable of taking up load within 10 minutes. Many storage resources, especially IBR storage, are well suited to this task as they are normally synchronized to the system and can ramp across their full load range in seconds to a few minutes, depending on how controls are programmed.

4.5 Load Following

Load following adjusts generator power output as demand (load) for electricity fluctuates throughout the day. A resource that is load-following reduces generation during periods of declining system load and increases generation during periods of increasing system load by AGC or manual dispatch. This is very similar to Regulating Reserve described above.

4.6 Ramping

Ramping is a term used to describe the loading or unloading of generation resources. Generation may be required to ramp for a variety of conditions including changes in system load, purchase or sale of energy, loss of generation or load, change in output of VERs, or merely the need to move a resource from one load level to another. Changes in the amount of non-dispatchable resources, system constraints, load behaviors, and the generation mix can affect the needed ramping capability and the amount of flexible resources needed to keep the system balanced in real-time. For areas with an increasing penetration of non-dispatchable resources, the consideration of system ramping capability is an important part of planning and operations. Most storage resources, especially some IBRs, can provide the needed ramping capability by quickly responding to AGC commands or manual dispatch instructions as compared to traditional generators.

4.7 Blackstart Capability

Blackstart capability is the ability of a resource to start without support from the system or to remain energized without connection to the rest of the system. Blackstart-capable resources can energize a bus, provide real and reactive power, and control frequency and voltage. Many storage systems can provide this service. IBR storage using grid-forming inverters that can establish a voltage and frequency reference are ideally suited to provide blackstart service.

Storage systems can provide an active reserve of power and energy within the grid. They can be used to energize transmission and distribution lines and provide station service power to bring conventional power plants online after a full or partial grid shutdown. Storage can provide a similar startup power to larger power plants, if the storage system is suitably sited and there is a clear transmission path to the power plant from the storage system's location. Further, storage systems can become a load if need to help stabilize the system as large generators come back online.

4.8 Voltage Support

Proper operation of the electric grid requires system voltage to be maintained within a specified bandwidth. Voltage support is provided by grid-connected equipment that generates, transmits, or uses electricity and often has or exhibits characteristics like those of inductors and capacitors in an electric circuit. To manage reactance at the grid level, system operators need voltage support resources to offset (provide or absorb) reactive energy so that the transmission system can remain stable. Energy storage resources can provide voltage support equivalent to conventional generators. IBR storage can, when properly designed, provide voltage support even when it is not actively delivering or absorbing real power from the system.

4.9 Observations and Gap Analysis

Energy storage can provide a wide range of ancillary services often equal to or better than conventional generators. Table 3 compares the ancillary service capability of conventional generation and energy storage resources.

Table 3: Comparison of ancillary service capability between conventional and energy storage resources.

Comparison Topic	Traditional Solution	Storage Solution
Frequency Control—Primary	In conventional synchronous generators, Primary Frequency Response is initiated automatically from a mechanical or electronic governor and is provided by stored energy in the rotating mass (inertia) or prime mover. This response typically is provided within seconds of the frequency excursion. The magnitude of response is determined by the governor droop setting.	Storage systems connected to the system by a synchronous generator (e.g., pump storage hydro) respond like any conventional generator. Response by inverter-based storage systems (e.g., battery energy systems) is initiated by electronic controls and is provided by withdrawing energy from the storage device or reducing energy going to the device. Frequency response should be proportional to the frequency deviation, similar to governor speed droop. This response can be provided in less than one second and is often referred to as fast frequency response.
Frequency Control—Secondary	Secondary Frequency Response is provided by automatic controls such as AGC or by manual redispatch to restore frequency to normal.	Similar to conventional generation, Secondary Frequency Response is provided by automatic controls such as AGC or manual redispatch.
Regulating Reserve	Online generation, controlled by AGC can provide both upside and downside regulating reserve if the generator has sufficient operating up/down bandwidth.	Energy storage systems (ESS) provide similar regulating reserve. These resources respond to AGC signals to increase or reduce output and, if allowed by operating controls and permits can also reduce or increase energy going to the ESS. Similar to conventional generation,

Comparison Topic	Traditional Solution	Storage Solution
		sufficient operating up/down bandwidth is required. Operators must also consider the impact on the storage SOC when regulating.
Flexibility Reserve	Unloaded and quick start generation, beyond that required for contingency and regulating reserve, is provided to meet the imbalance energy from VERs and the real-time ramping from this variability. This reserve is typically controlled through AGC supplemented by manual dispatch where needed.	Storage can provide the same flexibility reserve as conventional generation with the additional benefit that co-located and hybrid storage systems can manage the variability without affecting the grid.
Contingency Reserve	Unloaded and quick start generation provided to respond to a Balancing Contingency Event and other contingency requirements. This reserve is typically deployed through manual dispatch actions or by AGC.	Storage can provide Contingency Reserve in a manner nearly identical to conventional generation with the added benefit that storage would often be connected to the system even when not delivering or absorbing energy.
Load Following	Load following generally tracks changes in demand in the minutes-to-hours time frame. It differs from Frequency Regulation primarily because it is not a rapid-response function, nor does it directly seek to minimize ACE. Conventional generation can provide load following either through an AGC signal, by following a load schedule or manual dispatch command.	Energy storage is well-suited to load following because of its ability to act as an energy source or sink in response to load and generating capacity changes. Most types of storage can also respond much more quickly than typical synchronous generators when ramping is needed for load following.
Ramping	Conventional generation can move from one level to another by manual or AGC commands in response to ACE deviation, load changes or other	Same as conventional generation. Ramp rate for many storage types is extremely fast as there is often no mechanical or prime mover delay.

Comparison Topic	Traditional Solution	Storage Solution
	system operating parameters. The maximum ramp rate capability varies widely depending on generator type and programming.	Due to this high speed, it may be necessary to slow ramp rate under steady-state conditions.
Blackstart	Conventional generators require a source of energy to power auxiliaries and controls in order to start up. Examples of this energy source are batteries, diesel generator, stored energy in a pressure tank.	BESS, properly sized, and connected by grid forming inverters can energize station buses, lines, plant auxiliaries and system load during system start-up and restoration without the need for other onsite or offsite power. An additional benefit is the BESS can seamlessly switch to a load source to stabilize the system and provide frequency control.
Voltage Support	Conventional generation provides voltage support by over or under excitation of the generator. This excitation is electronically controlled and can follow a voltage, VAR, or power factor setpoint. The range of control for synchronous machines may be limited by ampere limits or loss of synchronism.	Similar to conventional generation, storage can provide high speed reactive power support. This support is typically limited by ampere rating on the equipment. For inverter-based storage, typical large generator interconnection agreement (LGIA) requires a +/- 0.95 pf capability although the actual equipment may be good for more.

5 Summary

As RPS and low-carbon goals for states and provinces within the Western Interconnection become commonplace, energy storage resources will play an increasingly important role as fewer fossil fuel resources are available to provide energy services. Load growth from electrification may continue to change the load curve requiring an increased ability to supply renewable energy throughout the day.

Energy storage technologies have a variety of unique operating characteristics that allow them to perform reliability services as well as or even better than conventional generation. These characteristics can enhance system reliability and resilience. Other characteristics will require increased focus on planning and real-time monitoring.

As increasing amounts of energy storage are deployed, it is becoming apparent that these technologies are a reliable source of energy. Proper placement of energy storage resources can reduce transmission congestion and defer the need for new transmission and distribution. These same resources can provide needed ancillary services, including the NERC-specified Essential Reliability Services. Further development of storage resources, including long-duration storage, will increase the value of storage and enhance its ability to replace retiring fossil fuel generation.