NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Energy Storage

Impacts of Electrochemical Utility-Scale Battery Energy Storage Systems on the Bulk Power System

February 2021

RELIABILITY | RESILIENCE | SECURITY

3353 Peachtree Road NE
Suite 600, North Tower
Atlanta, GA 30326
404-446-2560 | www.nerc.com

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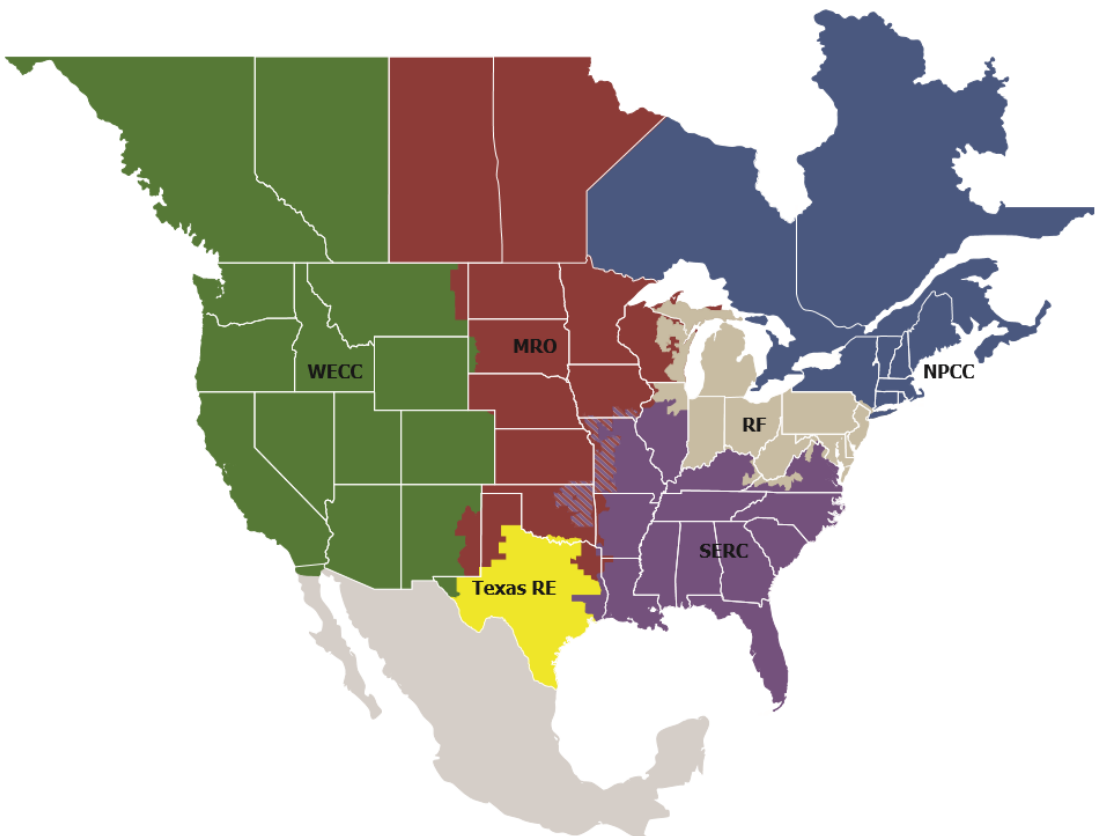
Preface

Electricity is a key component of the fabric of modern society and the Electric Reliability Organization (ERO) Enterprise serves to strengthen that fabric. The vision for the ERO Enterprise, which is comprised of the North American Electric Reliability Corporation (NERC) and the six Regional Entities (REs), is a highly reliable and secure North American bulk power system (BPS). Our mission is to assure the effective and efficient reduction of risks to the reliability and security of the grid.

Reliability | Resilience | Security

Because nearly 400 million citizens in North America are counting on us

The North American BPS is made up of six RE boundaries as shown in the map and corresponding table below. The multicolored area denotes overlap as some load-serving entities participate in one RE while associated Transmission Owners/Operators participate in another.



MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
Texas RE	Texas Reliability Entity
WECC	WECC

Executive Summary

The electricity sector is undergoing significant and rapid changes that present new challenges and opportunities for reliability, security, and resilience. NERC has recently conducted analyses that underscore challenges presented with the acceleration of coal-fired generation retirements and the increased reliance on natural gas. Additionally, NERC continues to note a rapid shift to inverter-based resources (IBRs) that are variable energy resources due to their fuel source (e.g. wind, solar) and have different operating characteristics from traditional synchronous generation. This variability creates potential challenges related to availability that may require additional resources to maintain BPS reliability. NERC has pointed to these topics in past assessments. Furthermore, NERC continues to emphasize the importance of ensuring that these IBRs provide essential reliability services (ERS) to the grid, such as frequency response, ramping, and voltage support. Along with this increase in IBR, primarily from the addition of a large contribution of renewable resources (e.g., wind, solar), there has been an increase in the application of battery energy storage systems (BESS) on the BPS. BESS have the ability to complement IBRs by providing some of the ERS that are important to maintain BPS reliability. Additionally, BESS provide elements of grid support, including providing flexible ramping support, fast frequency response (FFR), addressing the uncertainty of resource availability, and shifting energy to address new peaking conditions.

NERC recently conducted a joint study with WECC that underscored some of the potential benefits BESS can provide for FFR to avert using under frequency load shedding (UFLS) in response to generation losses. Additionally, this assessment confirms projections that BESS will grow significantly across the North American footprint over the next twenty years.

Key Findings: Based on data and information collected for this assessment, NERC identified the following:

- BESS are projected to grow at an increasing pace across the North American footprint as shown in **Figure 2.1**.
- Lithium-ion batteries account for more than 50% of the installed power and energy capacity of large-scale electrochemical batteries. Flow batteries are an emerging storage technology; however, it still constitutes only 2% of the market.
- Advances in technology, decreasing costs, and changes to FERC and other market rules will promote BESS growth.
- As IBRs (primarily from wind and solar resources) continue to grow, BESS can enhance grid reliability by offsetting resource variability and providing ERS, such as voltage support and frequency response. NERC's inverter-based working group (IBRWG) continues to develop appropriate guidelines addressing potential impacts of IBRs.[1]
- A joint NERC/WECC study determined that BESS strategically located provide effective and FFR to avert UFLS.
- Existing NERC standards adequately reflect battery storage as a generator, ensuring that the NERC TPL and MOD standards are applicable to the current number of BESS on the BPS.
- Data on battery storage tends to be non-uniform and lacking in consistency across reporting entities necessitating a need for better reporting mechanisms for BESS data.
- Because battery storage is an emerging technology, the development of utility-scale battery storage has lagged the integration of renewable resources.

Recommendations: Based on the identified Key Findings previously mentioned, NERC has formulated the following recommendations:

[1] IBRWG homepage

- System planners should prepare for a significant increase in the critical mass of BESS across the North American footprint. Planners must ensure that deployed battery storage provides the necessary ERSs to maintain BPS reliability, security, and resilience.
- As regulators provide more incentives for the viability of battery storage to provide capacity and energy, system planners must adequately plan the system for a projected large increase in BESS, understanding the impact of size, location, and operating characteristics on maintaining the reliable operation of the grid.
- The value of battery storage as a complement to variable energy resources, such as wind and solar, should be fully understood by system planners and operators. System planners must conduct adequate studies to determine the dynamic stability impacts of BESS' Interconnection, the capability to provide capacity to meet long-term and contingency reserve margin requirements, and the ability to provide ERS.
- NERC should conduct a detailed analysis of existing NERC Reliability Standards and guidelines to ensure that they adequately provide for a large increase in the critical mass of BESS, conduct a gap analysis to ensure that existing standards are not deficient, and/or identify the need for new standards to reflect the potential large increase in BESS.
- Entities that compile battery data information must enhance both their data collection methods as well as their reporting methods. As energy storage systems become more prolific, accurate and timely data will be essential for both system planners and operators. The Institute of Electrical and Electronics Engineers (IEEE) should update the IEEE Standards to reflect any implications of battery storage systems. The GADS Working Group should ensure that battery storage is accurately reflected in their data capturing protocols.
- The NERC Reliability and Security Technical Committee (RSTC) should form a task force to study the forward-looking implications of BESS and their overall effects on BPS reliability and resilience.

Introduction

NERC, in its mission to maintain the reliability of the BPS, continues to assess the implications on the reliability, security, and resilience from integration of cutting-edge technologies to the electrical grid. Due to the changing nature of the grid and the increasing amount of projected BESS in the future, the industry and regulators must pay more attention to BPS-connected BESS units.

What is a Battery?

The collective contribution of scientists and innovators created our understanding of the forces of electricity, but Alessandro Volta developed the first electrical battery in 1799.[2] This battery, known as the Voltaic Cell, consisted of two plates of different metals immersed in a chemical solution. He discovered that electricity can be generated chemically and made to flow evenly through a conductor in a closed circuit.

The basic power unit inside a battery is a cell, and it consists of three main parts. There are two electrodes (electrical terminals) and a chemical called an electrolyte in between them. The negative electrical terminal is the anode, and the positive electrical terminal is the cathode. Electrolytes allow ions to move between the electrodes and terminals allowing current to flow out of the battery to perform work. For our convenience and safety, these cells are usually packed inside a metal or plastic outer case. The difference between a battery and a cell is simply that a battery consists of two or more cells hooked up so their power adds together (**Figure I.1**).

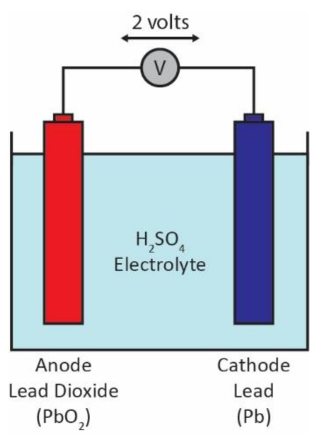


Figure I.1: Schematic of a Battery

Advances in technology and materials have greatly increased the reliability, output, and density of modern battery systems, and economies of scale have dramatically reduced the associated cost. Continued innovation created new technologies, like electrochemical capacitors, which can quickly charge or discharge energy for later use and provide an almost unlimited operational lifespan. Two emerging technologies in electric energy storage are**: Lithium-Ion and Flow** Batteries as described in this report; these two electrochemical technologies offer a more robust and adaptable energy grid, as shown in **Figure I.2**.

The scope of this report will include stand-alone BESS and BESS connected alongside other generation resources.[3] The BESS in scope for this assessment are BPS-connected with a primary emphasis on lithium-Ion and flow batteries. The fastest growing technology is the lithium-Ion market, which is largely driven by the electric vehicle (EV) market.

In recent years, the use of BPS-connected battery energy storage has quadrupled from 214 MW (2014) to 899 MW (2019), and NERC anticipates that the capacity could exceed 3,500 MW by 2023 (**Figure I.3**).

[2] https://ethw.org/Milestones:Volta's_Electrical_Battery_Invention,_1799

[3] This BESS configuration, referred to as hybrid resources, is typically a BESS with solar or a BESS with wind.

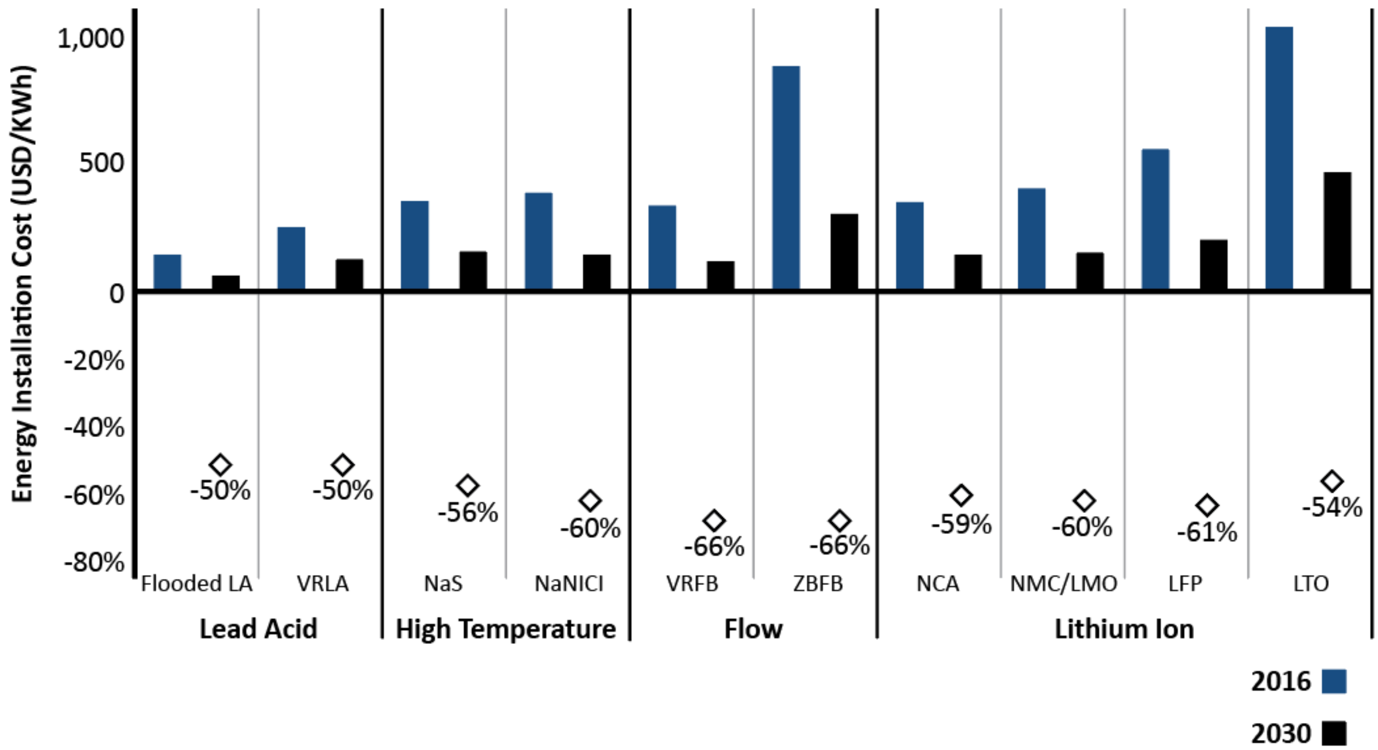


Figure I.2: Energy Installation Costs Central Estimate for Battery Technologies, 2016–2030
(The diamond represents the decrease in installation cost when comparing 2016 to 2030 data)

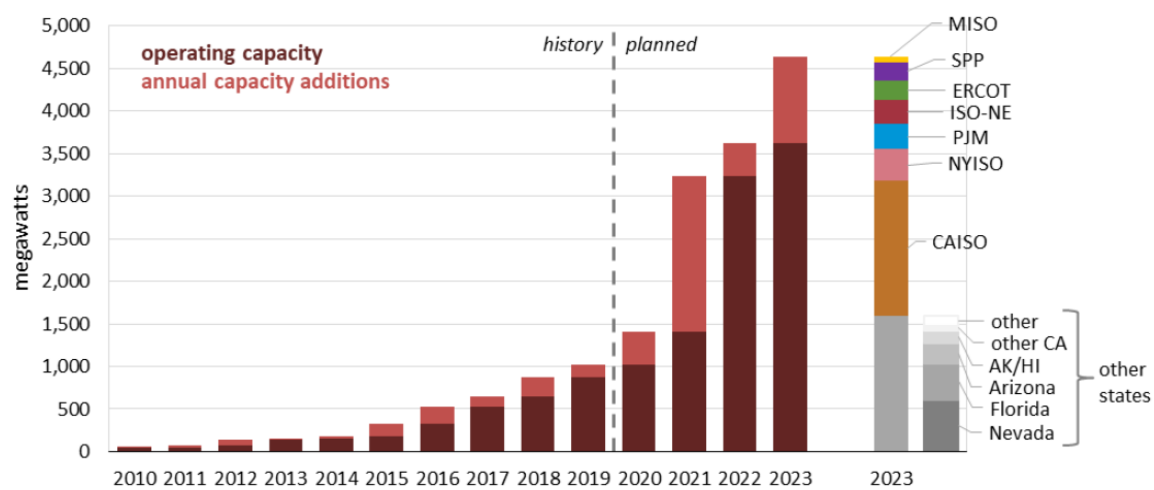


Figure I.3: United States BPS-Connected Battery Energy Storage Power Capacity (July 2020)[4]

One of the major growth areas for BESS is in hybrid systems. An example of a hybrid system is the combination of a wind or solar plant alongside a BESS facility. Internationally, a wind farm in South Australia retains the biggest-battery title at 100 MW/129 MWh, which is enough to supply 30,000 homes for eight hours. The largest battery in the United States and the world is projected to come online in 2021 when Florida Power and Light's 409 MW/900 MWh Manatee (center solar plant) Energy Storage Center becomes operational. Furthermore, Southern California Edison has just

[4] July 2020, U. S Energy Information Administration, Form EIA-806M, Preliminary Monthly Electric Generator Inventory

finalized what analysts called the nation's largest-ever purchase of battery storage in late April 2020, and this mega-battery storage facility is rated at 770 MW/3,080 MWh. The largest battery in Canada is projected to come online in 2021 when Alberta's TransAlta Renewables WindCharger's 60 MW utility-scale battery project becomes operational.[5]

The top four states that have operating or facilities under construction are California, Illinois, West Virginia, and Texas; these four states make up over half of the total installed battery storage in the United States, as shown in Figure I.4.

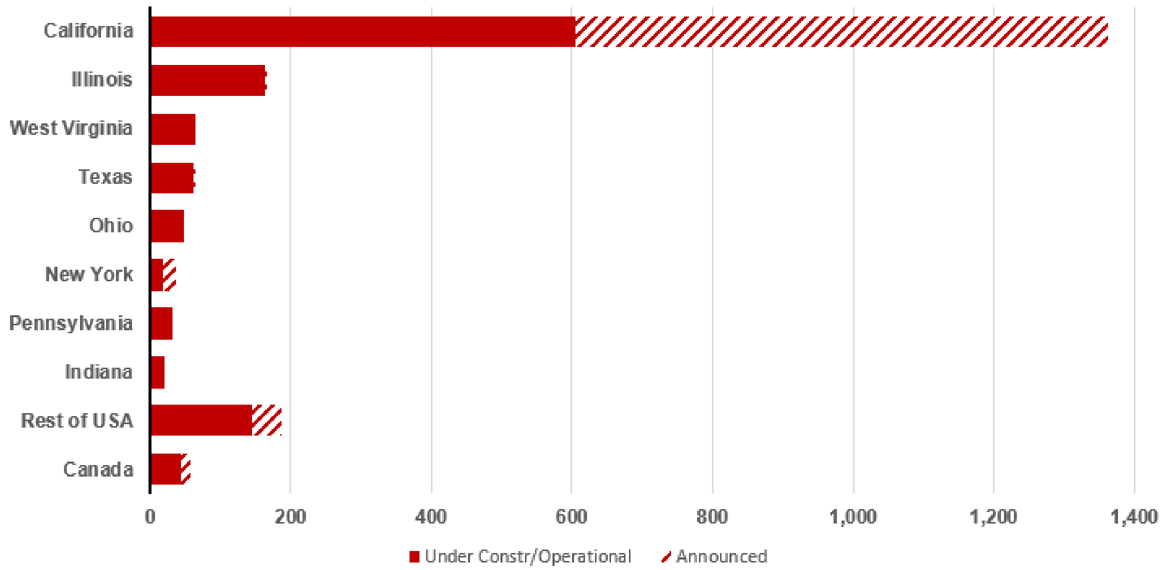


Figure I.4: United States Operating Utility-Scale Battery Storage by State[6]

Figure I.5 shows an electric power profile with its variations during a 24-hour period. In a load-leveling scenario, the BESS charges during periods of low power demand and discharges during periods of high power demand. Overall, the utility would need less capacity to meet this now lowered demand at its peak and could delay the installation of additional generating capacity. Such energy shifts help to regulate the generation and load balance. Energy storage would help to enable the delivery of energy for a limited amount of time when variable renewable energy sources, such as solar photovoltaic (PV) and wind, are not available.

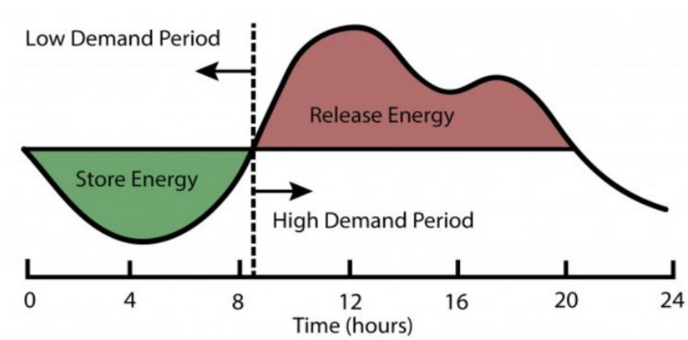


Figure I.5: Daily Energy Storage and Load Leveling[7]

[5] The first 20 MW is operational by December 2020, the final two 20 MW will come online in 2021; https://www.teslarati.com/tesla-canada-biggest-battery-energy-storage-system/

[6] Graph adapted from the DOE website, "DOE Global Energy Storage Database", Energy Storage Exchange, www.energystorageexchange.org.

[7] University of Michigan, http://css.umich.edu/factsheets/us-grid-energy-storage-factsheet

There are other applications and locations for BPS-level BESS. The three main demands that this technology is used for are operating reserves and ancillary services: energy arbitrage, curtailment reduction and load leveling, and peaking capacity.

While the daily energy storage and load-leveling example show a typical BESS applications case, the following sections summarize the most common applications for the growth of BESS in the power industry. These applications will dictate the operational characteristics of BESS.

Key Characteristics and Definitions of BESSs

Storage technologies have a few key characteristics that can be useful for comparison. Some of the key characteristics used by the industry are summarized below. These characteristics can be further defined and customized for each energy storage technologies.

Different battery technologies have an inherent state of charge (SOC), voltage currents, and temperature ranges that when operated within avoids accelerated cell degradation and safety issues.

Definition

A battery energy storage system (BESS) is a term used to describe the entire system, including the battery energy storage device along with any ancillary motors/pumps, power electronics, control electronics, and packaging. Since all electrochemical batteries produce dc current, a BESS typically consists of the following components:

- The dc battery system (batteries, racks, etc.)
- Enclosure(s) with thermal management
- Bi-directional dc/ac inverter
- EMS/system level software controller
- Switchgear/metering/MV step-up transformer, etc.

Rated Power Capacity *(citation, Grid-Scale Battery Storage, FAQ)*

The total possible instantaneous discharge capability, in kilowatts (kW) or megawatts (MW), of the BESS or the maximum rate of discharge that the BESS can achieve that starts from a fully charged state.

Rated Energy Capacity

The amount of energy stored in the battery, in kilowatt-hours (kWh) or megawatt-hours (MWh).

Rated energy capacity can be specified in ac terms (kWh) for complete systems, including energy storage medium, power conversion electronics, and transformers. Alternatively, it can also be specified in dc terms (MWh) when only the battery or energy storage medium is represented or considered. Additionally, vendors will sometimes show a “rating” for kWh in dc without or before considering ac conversion. When this is done, it is critical to remember that the power capacity of the system is normally determined by the capability of the power electronics, not just the energy storage medium, since the ac rating of a battery system may be significantly smaller than the dc rating of the battery component itself, due to the inefficiency of energy conversion.

Some manufacturers will specify a “rated power” but then list a “maximum depth-of-discharge” (DOD) that limits the actual energy available. For some technologies, the energy available may be proportional to the discharge rate and temperature (higher discharge rates typically allow less energy to be removed from the battery).

Storage Duration
Storage duration is the amount of time the energy storage can discharge at the system power capacity before depleting its energy capacity. For example, a rated battery with 1 MW of power capacity and 4 MWh of usable system energy capacity will have a reserve duration of four hours at a specified discharge rate.

Cycle Life
This characteristic is specific to the battery/energy storage medium. Cycle life is the number of times the battery can be discharged and recharged during its useful life over a specific SOC range. Cycle life is often specified as number of cycles to a specific depth of discharge (DOD) since many batteries will have a longer life if discharges are kept shallow. This assumes that cycle life is directionally proportional to DOD and is equivalent to something like 5,000 cycles to 50% DOD or 2,500 cycles to 100% DOD. This may not be the case for some battery types and chemistries. There is an increasing trend to provide warranties based on “energy throughput.” This is derived by the summation of the total amount of energy a battery is expected to deliver over its lifetime (e.g., the number of kWh, stored energy delivered by the battery). This term is universal and can be apply to all types of batteries no matter what their degradation mechanism or rate is over time.

Self-discharge
Self-discharge occurs when the stored charge (or energy) of the battery is reduced through internal chemical reactions or without being discharged to perform work for the grid or a customer. Self-discharge, expressed as a percentage of charge lost over a certain period, reduces the amount of energy available for discharge and is an important parameter to consider in batteries intended for longer-duration applications.

State of Charge
SOC, expressed as a percentage, represents the battery’s present level of charge and ranges from completely discharged to fully charged. The SOC influences a battery’s ability to provide energy or ancillary services to the grid at any given time. Different battery technologies have an inherent SOC range that, when operated within, avoids accelerated cell degradation. The achievable high and low SOC values are specific to a battery chemistry and type.

Round-trip efficiency
Round-trip efficiency, which is measured as a percentage, is a ratio of the energy charged to the battery to the energy discharged from the battery. It represents the total efficiency of the battery system to resupply energy taken from its source, including losses from self-discharge. Although battery manufacturers often refer to the dc-dc efficiency (i.e., round-trip efficiency from the dc charge controller) and do not include the losses due to required subsystems, such as HVAC, natural gas detection, and fire protection. In contrast, ac-ac efficiency (i.e. the round-trip efficiency from the point of interconnection) includes all system losses that are typically more important as it measures the battery as it is charging and discharging from the point of interconnection to the power system, which uses ac (Denholm 2019).

System Life
This is the expected calendar life of the BESS used for its designed purpose and intent, also known as installation life. The system life incorporates the expected service life, degradation mechanism, and rate of all subcomponents for an application or use case. This includes but is not limited to the following: battery, electronics, power conversion, and interconnection equipment. Typically, this term is used only for the battery degradation, which may be a factor of cell corrosion, capacity degradation, life of seals/membranes, or other factors. If designed and installed properly, battery degradation is truly dependent on how an end user operates their system. Battery applications are typically broken up into two categories: energy and power. Energy applications can include time shift, supply capacity, and spinning reserves. Power applications are typically load ramping and/or following voltage support and frequency response. Because energy response typically has a deeper depth of discharge on a consistent basis, these applications have a steeper degradation curve for some chemistries.

Using the battery outside its designed purpose may affect its capabilities and life. Changing or modifying the use case, cycle frequency, DOD, charge/discharge parameters, or rate will affect the warranty of the battery and may exceed the battery or the power electronic capabilities. Entities should contact battery manufacturers and evaluate any effects of changing the use case from the original design before making changes to installations or subcomponents.

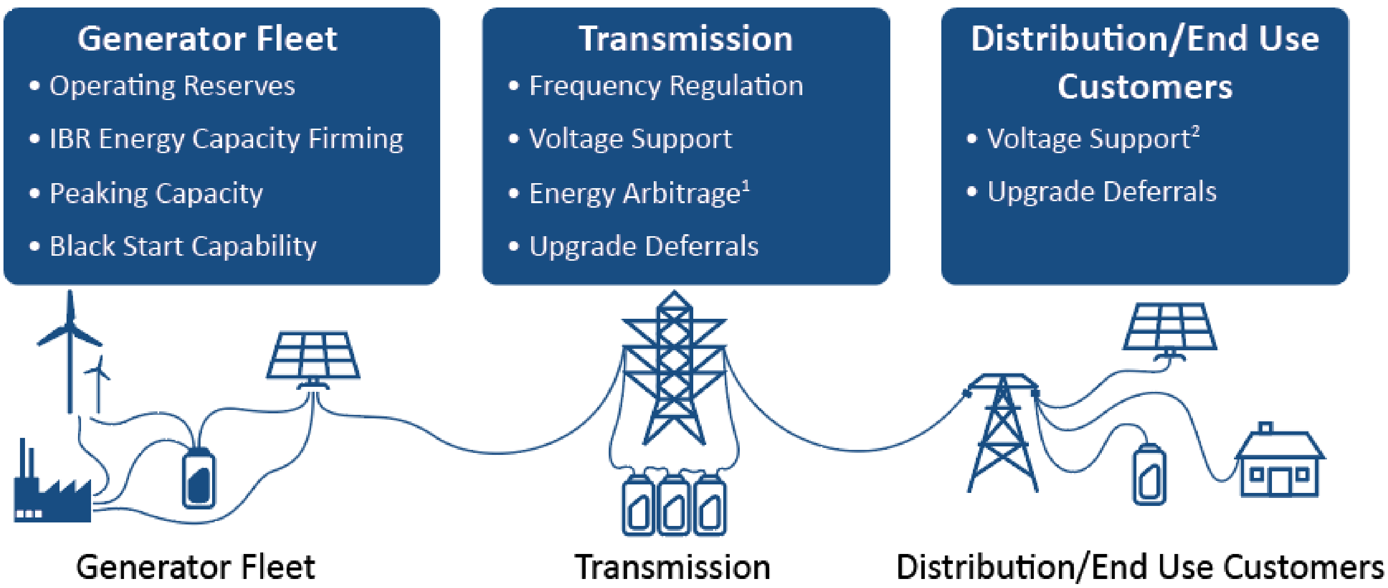
Safety

If used incorrectly, all batteries become a risk and can pose a danger to the equipment and personnel. The higher the energy density of the battery means the more attention to the design, maintenance, and operation of the BESS is required.

Chapter 1: Applications of Battery Energy Storage for the Grid

BESS are an well suited technology to provide short-term grid contingency support (tens of seconds) and long-term energy support/reserve (up to four hours) with the BESS capable of short settling times and the operational flexibility inherent to energy storage. BESS can provide the ERS of frequency regulation, ramping, and voltage support in a manner that can replicate current levels of ERS from synchronous facilities. In addition, BESS can also provide ancillary services with several hours of energy capacity reserve ready for the grid. The main BESS applications in power system generation, transmission, and operation are described in **Figure 1.1**.[8]

Batteries can provide services for system operation and for solar PV and wind generators as well as defer investments in peak generation.



[1] This term is related to the load-leveling term commonly found in nonmarket solutions. They both effectively look to have similar battery performance by shifting energy to different times.

[2] While not commonly used for distribution systems, BESS can perform their voltage support on the distribution system. It is expected that most BESS that provide voltage support will be placed on the transmission system.

Figure 1.1: Main Battery Applications in the Grid[9]

The following section identifies the major reported services BESS are providing.

Operating Reserves and Frequency Regulation

The ability to maintain specified reserves and/or adequate reserves beyond the firm system demand describes the function of operating reserves. Operating reserves consist of attributes like regulation, load following, and contingency reserves (spinning, non-spinning, and supplemental).[10] BESS can provide the regulation and load following capability to supply/absorb additional energy for the unexpected grid energy imbalance, or they can provide ramping capability of the grid during times of major load shifts.[11] With provided flexible ramping capability,

[8] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2019/Sep/IRENA_Utility-scale-batteries_2019.pdf

[9] IBR in **Figure 1.1** are inverter-based resources.

[10] https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Concept%20Paper.pdf

[11] These are typically the morning, afternoon, and evening times that are exacerbated by high solar PV penetration.

BESS can help BAs respond to large ramps during the day and reduce any ramping rate requirement of other resources.

BESS can also provide the grid primary frequency response (PFR). BESS have FFR capability as a full-converter type of power electronic device that, if enabled, allows the BESS to provide a large power injection before most conventional generation. These two functions, PFT and FFR, are short-term reliability services. BESS can also provide longer-duration frequency services with the stored energy that can provide grid the secondary frequency response or tertiary frequency response.

Voltage support

Generating facilities are required to provide reactive power to the grid as called for in NERC's Reliability Standards. BESS can provide the reactive needed to support grid voltage stability on the transmission system. BESS can be a reactive resource to provide local voltage support acting as a transmission asset that similar to shunt reactive devices,[12] such as capacitor, static VAR Compensator (SVC), capacitors, or other power electronic controlled devices. This can occur independently from or in parallel with their frequency regulation service.

Inverter-Based Resources (IBR) Energy Capacity Firming

Renewable energy resources, such as wind plants and solar PV, are variable energy resources as their "fuel source" is inherently variable (wind speed and solar irradiation). BESS can support renewable energy resources by providing energy during times of intermittent or expected unavailability (i.e., at times when the wind speed drops for wind generation or at night for solar PV). The addition of BESS can result in a higher capacity factor for the hybrid system.

Peaking Capacity

BESS can discharge energy at the peak loading conditions to meet the peak demand as well as provide peaking generation capacity replacing the need to use high cost natural gas plants that have historically been dispatched during peak seasons. Furthermore, BESS can ameliorate congestion issues and serve as a substitute for peak shaving.

Energy Arbitrage

BESS can take the advantage of different energy market prices by charging battery during low price hours and discharging during peak price hours.

Transmission and Distribution Upgrade Deferrals

When the peak electricity demand exceeds the existing electricity grid's transmission and distribution capacity, the grid's infrastructure should be upgraded to deliver energy to the end-use customer or demand response options explored. However, these upgrades can be expensive to meet a limitation that may only occur for a few hours of the year.

BESS can help alleviate the peak demand stresses on the system. BESS can reduce grid congestion and improve overall transmission and distribution asset use especially with mobile BESS that can be BESS relocated to new areas when they are no longer needed in the original location.

Blackstart Capability

Following a power system blackout, system blackstart capability serves to provide an initial start-up power supply for the other synchronous generators restoration and re-energize the transmission system without normal grid support. A BESS can be a potential blackstart resource as the stored energy lasts hours and can provide initial start-up power for itself and other generation facilities.

[12] Shunt reactive devices are a parallel pathway to ground in order to provide a service to the electricity grid, typically on managing reactive power. These are different from series-connected resources.

Figure I.2 shows the cumulative installed capacity (MW) for BPS-connected storage systems in the United States in 2019 by the service the systems provide. Operating reserves and ancillary services make up a large portion of these MWs of cumulative installed capacity.

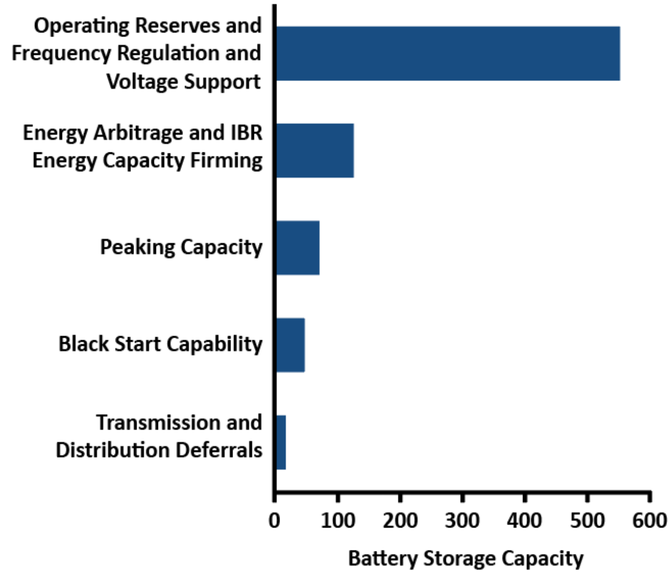


Figure 1.2: United States BPS-Connected Battery Energy Storage Capacity by Service[13]

Status of Rated Power (MW) and Energy (MWh)

The impact that BESS can have on the future sustainable energy grid is substantial. As of September 2020, the United States and Canada had over 37 GW of rated power in energy storage with 90% coming from pumped hydro (Figure 1.3). The remaining 10% is from lithium-ion, thermal storage, compressed air, flywheel, lead batteries, and flow batteries. The most dominant electrochemical storage technology is lithium-ion, which accounts for about half the installed rated power.

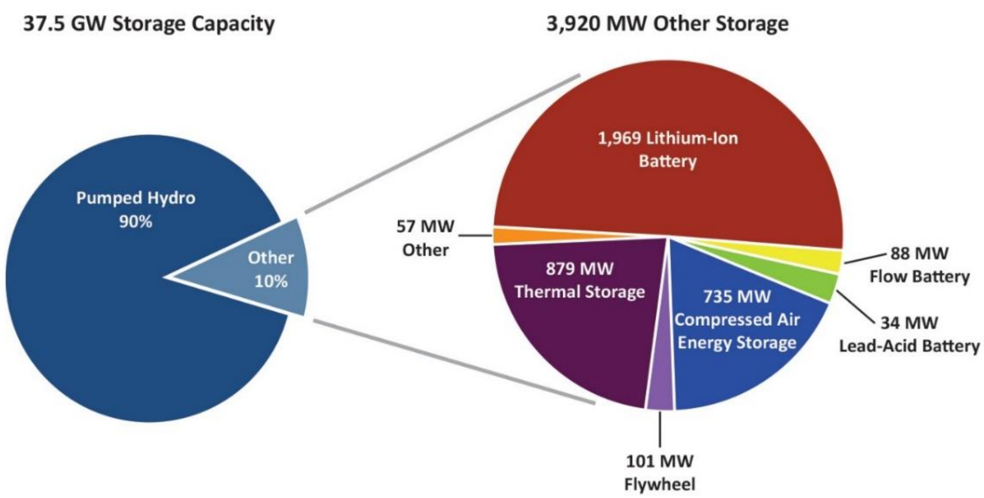


Figure 1.3: Electric Storage Capacity in the United States and Canada, by Type of Storage Technology[14]

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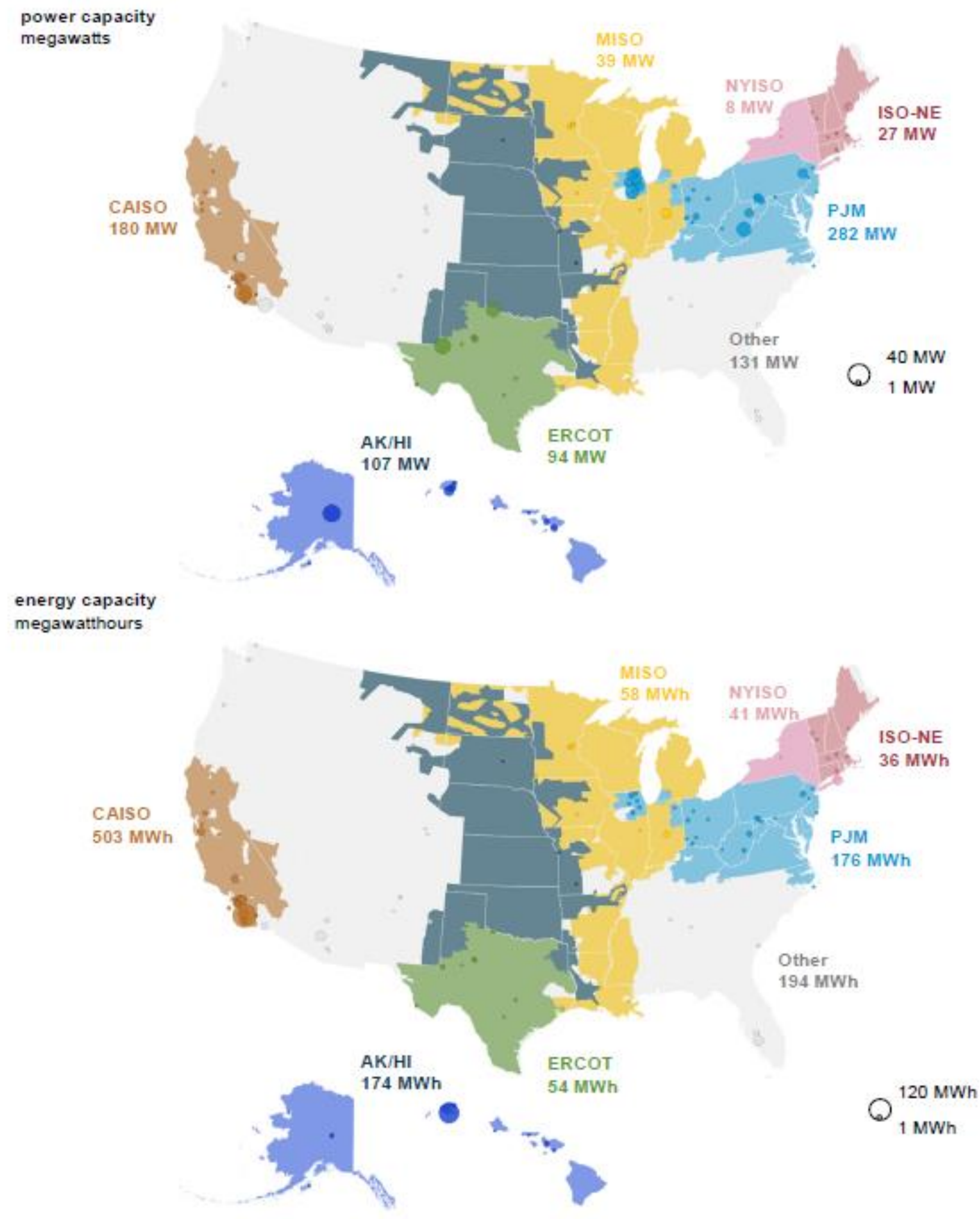
[13] https://www.nrel.gov/docs/fy19osti/74426.pdf

[14] Graph adapted from the DOE website, "DOE Global Energy Storage Database," Energy Storage Exchange, www.energystorageexchange.org.

Another view of battery storage technologies across the regulated ISO/RTO markets is shown in **Figure 1.4**. Power capacity (MW) is 282 MW for PJM, 180 MW for CAL-ISO, and 94 MW for ERCOT; the energy capacity (MWh) is 176 MWh for PJM, 503 MWh for CAL-ISO, and 54 MWh for ERCOT.



Sources: U.S. Energy Information Administration, Form EIA-860M, *Preliminary Monthly Electric Generator Inventory;* U.S. Energy Information Administration, Form EIA-860, *Annual Electric Generator Report* Note: Energy capacity data for large-scale battery storage installed in 2018 are based on preliminary estimates.

Figure 1.4: United States Grid-Connected Energy Storage Projects

Chapter 2: Lithium-Ion and Flow Batteries

The U.S. Department of Energy projects that, by year 2050, 35% of the United States energy will come from wind (404 GWs of capacity)[15] and 27% will come from solar PV (632 GWs of capacity).[16] Similarly, BloombergNEF projected the whole world energy storage installations (including electric vehicles and not including pumped hydropower) will multiply exponentially, from 9 GW deployed as of 2018 to 1,200 GW lithium-ion batteries by 2050.[17] The United States has the fastest growth rate of energy storage worldwide and it is anticipated that the United States will lead the significant growth of BESS. See **Figure 2.1** that demonstrates this exponential growth.

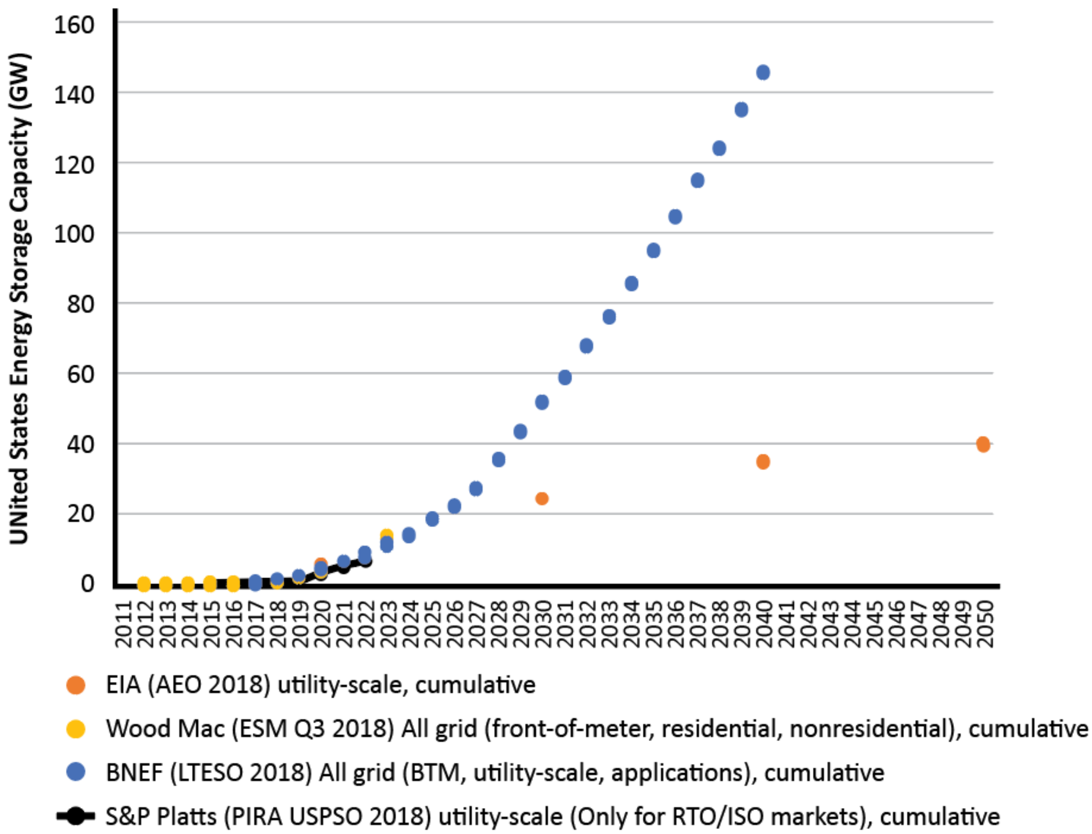


Figure 2.1: Exponential Growth Projected for Electrochemical Storage[18]

Cost Trends

The cost of batteries is projected to continue to fall over the medium- to long-term. However, the rate of decrease is likely to vary significantly by battery technology. Likewise, the various components of a BESS are likely to decrease at different rates based on variables like the level of standardization, economies of scale, and industry learning.

BESS costs are typically described in two ways:

- **Cost per kW (MW):** This is the total installed cost of the system divided by the instantaneous output power rating of the system. The units are either $/kW-ac (preferred) or $/kW-dc.

[15] https://www.energy.gov/sites/prod/files/wind_vision_highlights.pdf
[16] https://www.energy.gov/sites/prod/files/SunShot%20Vision%20Study.pdf
[17] https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf
[18] https://www.pnmforwardtogether.com/assets/uploads/PNM-IRP-Nov-19-2019.pdf

- **Cost per kWh (MWh):** This is the cost of the system divided by its projected energy output. The appropriate unit of measure is $/kWh-ac (preferred) or $/kWh-dc. One must also specify whether this is based on the useable storage capacity versus the rated storage capacity, if different. In addition, for any given BESS, this cost metric can be expressed in the following ways:
  - **Installed cost:** This includes the equipment cost of the battery, balance of system costs, and any engineering, procurement, and construction costs.
  - **Levelized cost:** This is the "all-in" cost to design, construct, and use of the BESS over the course of its useful life. Notably, this includes maintenance costs, effects of battery degradation (i.e., decreased output), etc. When comparing a BESS against an alternative resource, the levelized cost of storage (LCOS) is the preferred unit of measurement. The levelized cost is a function of both system cost and expected life. Even though lead acid batteries are relatively inexpensive, their low cycle life makes each charge/discharge cycle expensive, precluding them from energy market participation under most circumstances (**Figure 2.2**).
  - Improvements from the past five years have pushed the levelized capital cost down significantly.[19]

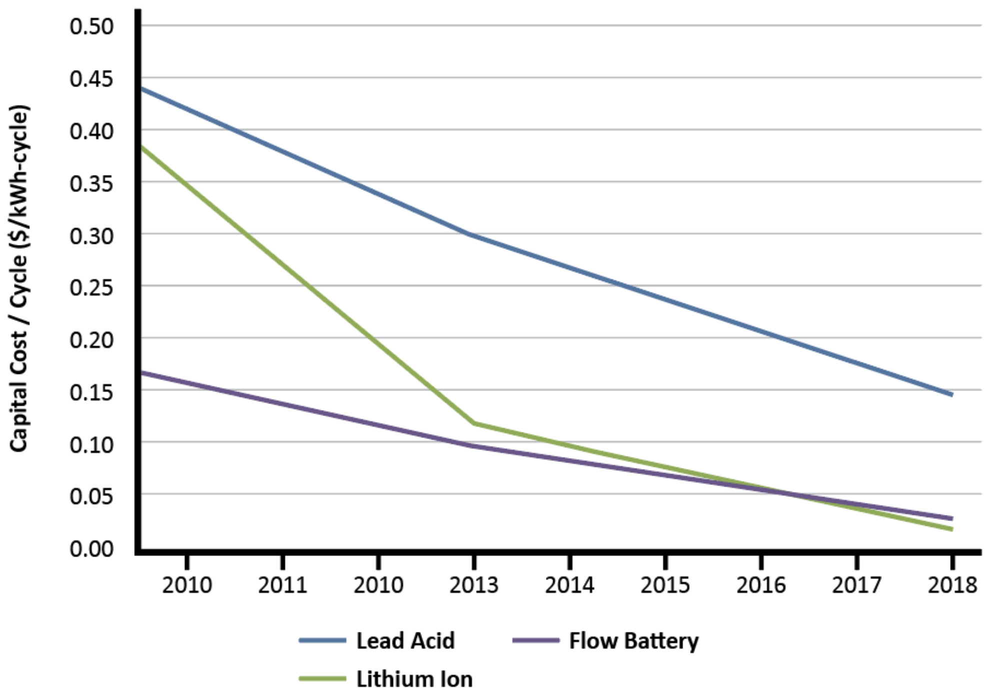


Figure 2.2: Estimated Levelized Capital Costs of Battery Storage[20]

Electricity Storage Technologies

There are many electricity storage technologies at or near commercial viability with many more at various stages of development. This area is rapidly evolving and a summary of the categories in current technologies are mechanical, electrochemical, thermal, electrical, and chemical, as shown in **Figure 2.3**.

[19] Lazard (2018), Lazard's Levelized Cost of Storage Analysis – Version 4.0

[20] Energy Storage Association, Storage Technology Primer

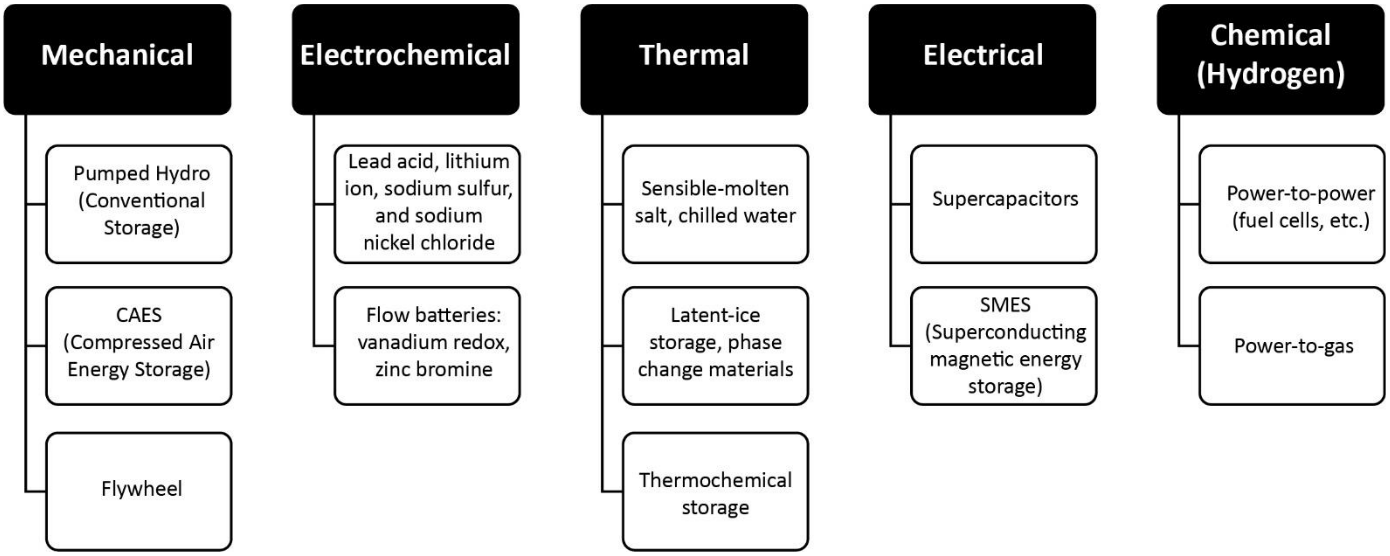


Figure 2.3: Classification of Storage Technologies[21]

The most commercially viable technologies are lithium-ion and flow batteries due to the cost of storage, efficiency of storage, and energy price spreads.

Lithium-Ion

The basic premise for electrochemical storage is that it uses electricity to drive a chemical reaction while charging and then it reverses that reaction to release electricity when discharging. Lithium-ion is the dominant storage technology because of its moderate cost, high efficiency, and long lifetime. These characteristics make lithium-ion batteries well suited for the frequency regulation market.

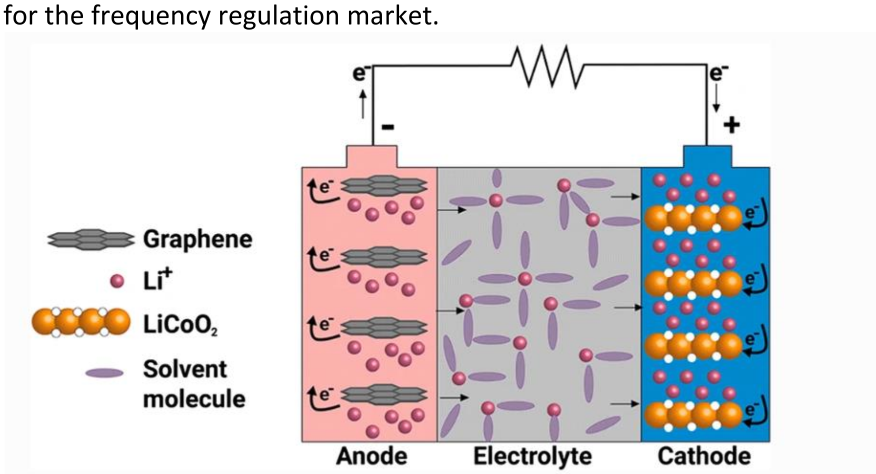


Figure 2.4: Ion flow in lithium-Ion battery[22]

[21] Energy Storage battery types, https://energystorage.pnnl.gov/batterytypes.asp, Energy Storage Association, Storage Technology Primer

[22] Argyrou MC, Christodoulides P, Kalogirou SA (2018). Energy storage for electricity generation and related processes: technologies appraisal and grid scale applications. Renew Sustain Energy Rev 94:804–821

A summary of some of the advantages and disadvantages of lithium-ion battery technology is shown in **Table 2.1**.

Table 2.1: Advantages and Disadvantages of Lithium-Ion BESS[23]	
Advantages	**Disadvantages**
They have high specific energy and high load capabilities with power cells.	They require protection circuits to prevent thermal runaway/fire that could destroy the BESS.
They have a long cycle and extended shelf life as well as being maintenance free.	They degrade at high temperatures and when stored at high voltage.
They have high capacity, low internal resistance, and good Coulombic efficiency.	No rapid charge is possible at freezing temperatures (<0°C, <32°F).
They have a simple charge algorithm and reasonable short chart times.	Transportation regulations are required when shipping these batteries in larger quantities.
They have low self-discharge (less than half that of Nickel Cadmium and Nickel-metal Hydride) NiMH.	Life cycle issues, such as decommissioning issues, need to be considered (e.g., the disposal of hazardous materials).

Lithium-ion batteries can store a large amount of energy in a small space but are notoriously flammable, as noted in a number of high profile incidents involving cell phones, airplanes, and electric cars. Some chemistries are inherently more flammable than others, but designers can also influence flammability through different choices of electrolyte, separators, physical packaging, and cooling systems. As battery storage continues to grow in its importance, system planners need to understand technological limitations as well as risks with lithium-ion batteries.

Flow Batteries

Unlike solid-state batteries, flow batteries store energy in liquid chemicals that are pumped through a reaction area for charging and discharging. This has the advantage of enabling the storage capacity to be increased by increasing its reservoirs. The first patent for a titanium chloride flow battery was granted in July 1954. The present day vanadium redox battery was patented in 1986 by the University of New South Wales in Australia.

A flow battery is a cross between a conventional battery and a fuel cell. A liquid electrolyte of metallic salts is pumped through a core that consists of a positive and negative electrode separated by a membrane. The ion exchange that occurs between the cathode and anode generates electricity. Most commercial flow batteries use sulfuric acid with vanadium salt as the electrolyte. The electrodes are made of graphite bipolar plates. Vanadium is one of few available active materials that keeps corrosion under control. Activated by pumps, flow batteries perform best at a size that is greater than 20 kWh. Flow batteries can typically deliver more than 10,000 full cycles and are good for about 20 years. **Figure 2.5** illustrates the flow battery concept.

The electrolyte is stored in tanks. To increase the energy density, the tank sizes can be doubled by using ready-made storage tanks at an estimated cost increase of only 50% compared to a new system. An issue that occurs is that the membranes tend to corrode and are expensive; this can be mitigated by using additives.

[23] Battery University website: https://batteryuniversity.com/learn/article/lithium_based_batteries

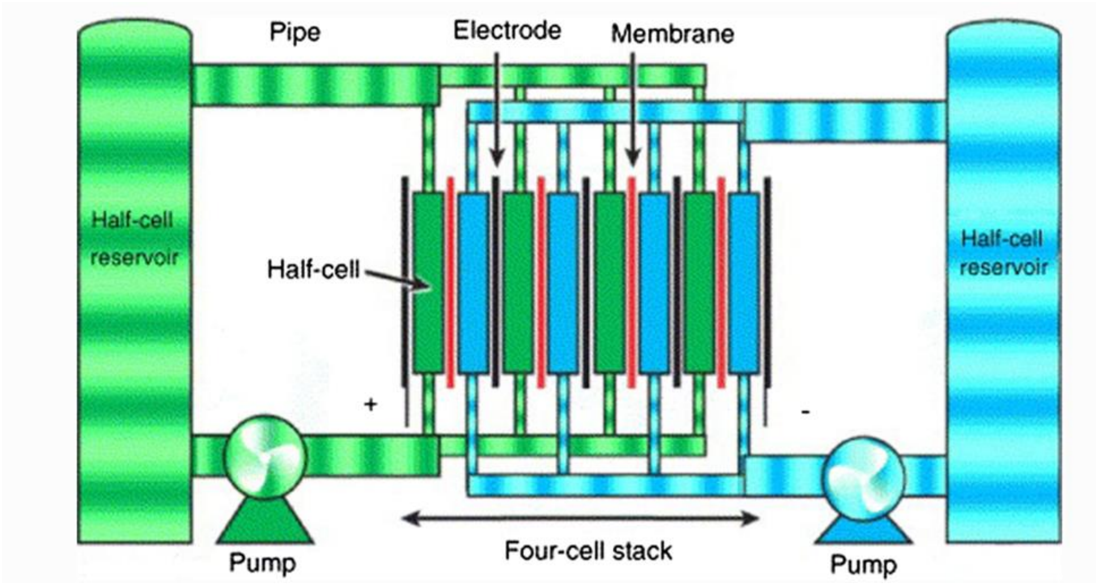


Figure 2.5: Schematic of Flow Batteries

The electrolyte is stored in tanks and pumped through the core to generate electricity; charging is the process in reverse. The volume of the electrolyte governs its battery capacity.[24]

Large-scale flow batteries exceeding 100 kWh have been in use in Japan since 1996. There is also a move towards cost and size reduction. Rather than building a large battery resembling a chemical plant, newer systems come in container-sizes of typically 250 kWh that can be stacked. Modern flow batteries are also starting to emerge in Europe.

Just like any other technology, there are advantages and disadvantages for flow battery energy storage, summarized in **Table 2.2**.[25]

Table 2.2: Advantages and Disadvantages of Flow BESS

Advantages	Disadvantages
External electrolyte storing enables independent power and energy adjustment to specific applications (wide range of E/P ratios is possible).	Chemical handling with potential leakage of acidic solutions can pose a complication.
They have achieved a relatively high conversion efficiency.	The need for sensors. Pumping and flow management mechanisms may increase maintenance costs.
They possess a high cycle life and durability as well as sustained performance over lifetime and are aided by absence of morphological changes in electrodes.	There is a high cost of some active materials or key system elements, such as membrane or electrolyte storage vessels.

[24] Van Der Linden S (2006) Bulk energy storage potential in the United States, current developments, and future prospects. Energy 31(15):3446–3457

[25] International Renewable Energy Agency, based on Li and Liu, 2017; Sensible, 2016; Skyllas-Kazacos et al, 2011; Linden and Reddy, 2002.

Chapter 3: Battery Energy Storage for the North American Footprint

United States Energy Information Administration

In the United States, EIA projects that battery storage is expected to continue to grow at an accelerated pace through 2050. **Figure 3.1** shows Annual Energy Outlook (AEO)[26] projections of battery storage penetration given several assumptions around the continued growth of renewables coupled with the decline in fossil fuel generation.

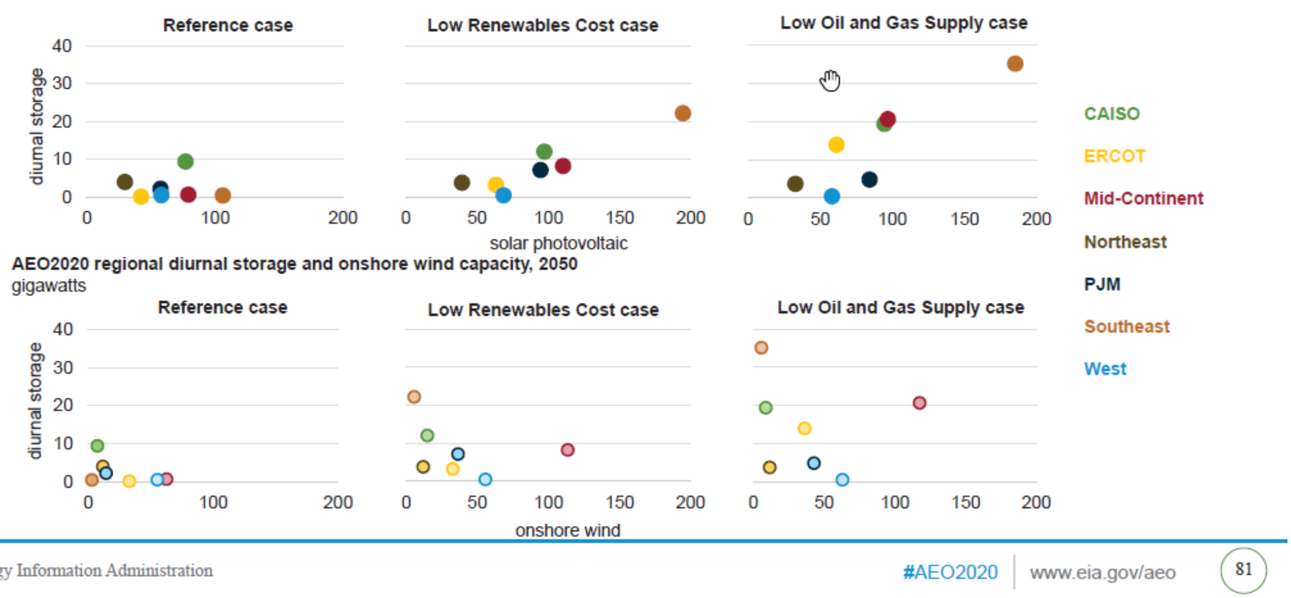


Figure 3.1: Growth in Utility-Scale Battery Storage following Growth in Solar

Hybrid plants are increasingly popular as storage is added to planned and existing renewable energy power plants. The EIA provides a breakdown of the number of facilities that are hybrid BESS plants and an in-depth view of the applications the batteries are serving at these plants. These hybrid plants shown are either wind or solar generation co-located with batteries. **Figure 3.2** (arrows) shows 19 hybrid renewable-BESS existed in 2016 with that number climbing to 53 in 2019. The EIA projects that the number of sites will double by 2023. **Figure 3.2** also shows the gigawatts of capacity that is operating as of February 2020 as well as a projection to the end of 2023.

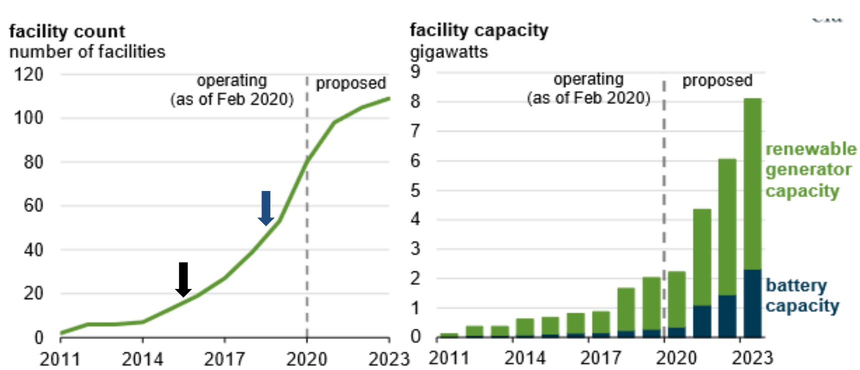


Figure 3.2: Count and Capacity of Renewable Hybrid Facilities in the United States (2011–2023)

[26] https://www.eia.gov/outlooks/aeo/

Figure 3.3 breaks down the total number of facilities that operate as wind/solar with a battery along with the number of facilities performing a specific function. The most popular function currently served as of 2018 is the storage of excess wind and solar energy to prevent curtailment of these resources when the wind decreases or the sun does not shine. Arbitrage is seemingly unpopular with only 3 of the 43 facilities serving this function.

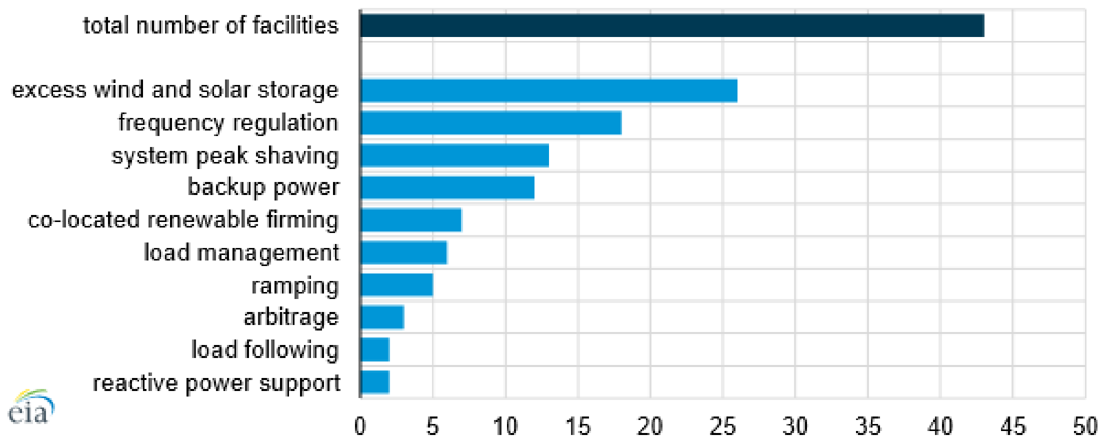


Figure 3.3: Applications Served by Utility-Scale Batteries at Renewable Hybrid Facilities (2018)

Figure 3.4 details the planned renewable plus storage capacity by state for the top ten states. The EIA details that over 90% of the total operating hybrid capacity (renewable generator plus energy storage) capacity in the country is located in just nine states. In addition, Texas alone holds 46% of the current total. Although nearly 25% of the total United States battery capacity is installed as part of a hybrid system, only 1% of total wind capacity and 2% of total solar capacity is part of a hybrid system. Many of these future projects result from state initiatives to reach renewable goals set forth for the electricity generation sector. The planned batteries are becoming increasingly larger as the cost of energy storage becomes cheaper.

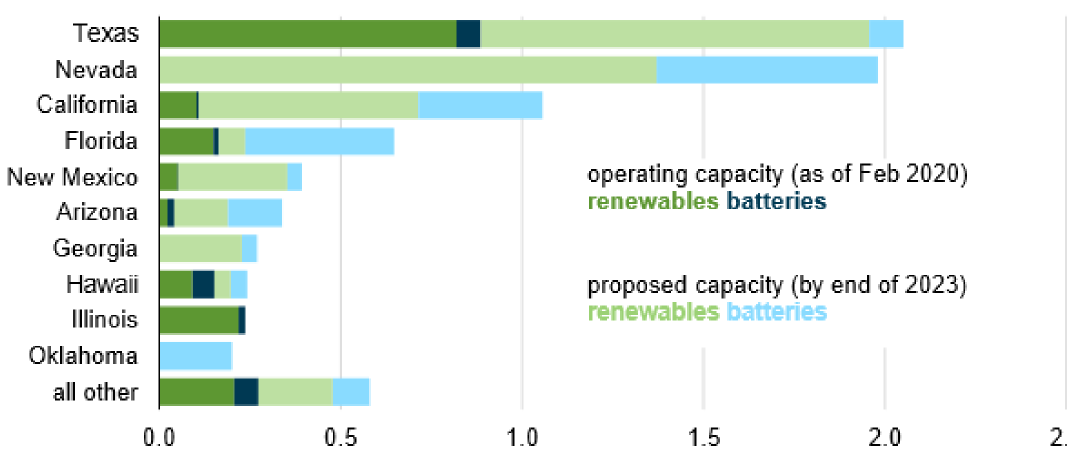


Figure 3.4: Operating and Planned Renewable plus Storage Capacity in GW for Top 10 States

Chapter 4: NERC–WECC Study on BESS Fast Frequency Response

NERC and the Reliability Issues Steering Committee (RISC) have identified the changing resource mix and the corresponding necessary changes of BPS planning as two of the critical risks and challenges to BPS reliability.[27] NERC and WECC have developed a joint study to assess the Western Interconnection (WI) grid dynamic frequency stability impact of the large penetrations of renewable energy resources and the support of fast frequency response (FFR) from BESS.

Projections of BESS in the Western Interconnection Grid

BESS are experiencing rapid growth in both the BPS and distribution power systems due to declining costs and the ability to provide reliable grid stability support. BESS provide a variety of differing products, one of which is the support of BPS frequency during grid events by supplying FFR.

One of the largest growth areas of BESS projects has been in California. In May 2020, PG&E announced five new BESS projects that are scheduled to come on-line by August 2021 (**Table 4.1**).[28] By 2023, PG&E will have awarded BESS contracts that total more than 1 GW capacity, which is more than double the capacity.

Table 4.1: PG&E Batteries On-Line

Counterparty /Project Name	Storage Technology	Term (years)	Size (MW)
Dynegy Marketing and Trade, LLC/Project	Lithium Ion Batteries	10	100
Diablo Energy Storage, LLC/Project	Lithium Ion Batteries	15	150
Gateway Energy Storage, LLC/Project	Lithium Ion Batteries	15	50
NextEra Energy Resource Development, LLC /(Blythe Energy storage Project)	Lithium Ion Batteries	15	63
Coso Battery Storage, LLC/Project	Lithium Ion Batteries	15	60
		Total Capacity	**423**

As IBRs have grown and BESS continue to grow and evolve, it becomes important to understand how battery storage can help mitigate or prevent events on the interconnected system. Events that can initiate under frequency load shed (UFLS) schemes are a threat to reliability. Over the past several years, significant events have occurred across the globe that have resulted in UFLS: Australia had two grid separations and load loss event in 2018[29] and 2019[30]and the National Grid in the United Kingdom had a blackout in 2019.[31] These events occurred in areas that have experienced significant increases in IBRs. In the United Kingdom event, BESS have helped the overall system[32] but not enough to restore frequency to a level that could avoid UFLS. From the 2018 South Australia (SA) event final report, the large-scale battery storage was valuable in this event as it assisted to mitigate the initial decline in system frequency. In addition, it provided balancing support for the fluctuating frequency and rapidly changed the output from discharging

[27] https://www.nerc.com/comm/RISC/Related%20Files%20DL/ERO_Reliability_Risk_Priorities_RISC_Reccommendations_Board_Approved_Nov_2016.pdf

[28] https://www.pge.com/en/about/newsroom/newsdetails/index.page?title=20200519_pge_poised_to_expand_battery_energy_storage_capacity_by_more_than_420_megawatts

[29] https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2018/Qld---SA-Separation-25-August-2018-Incident-Report.pdf

[30] https://www.aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2019/final-report-sa-and-victoria-separation-event-16-november-2019.pdf?la=en&hash=231CA53842A89C65036F1F288D0DCF73

[31] https://www.ofgem.gov.uk/system/files/docs/2019/09/eso_technical_report_-_final.pdf

[32] https://www.current-news.co.uk/blogs/batteries-and-black-outs-how-storage-helped-bring-the-uk-system-back-online-and-how-they-could-do-more

to charging as needed to limit the over and under frequency conditions in SA following the SA separation from the rest of Australia. These events lead to the need for additional studies to determine how BESS can be used for FFR to rapidly support grid frequency when large generator trip events occur along with a large penetration of IBRs.

NERC and WECC Study Scope

With the increasing penetration of IBRs and retirement of synchronous generators that provide inertial and PFR support to the grid frequency stability, the NERC/WECC joint study investigates how BESS can support and improve grid frequency stability. The study scope was limited to BPS connected BESS devices and did not include devices interconnected through the distribution system. The main objectives of the study included the evaluation of the following:

- The WI grid light load case with low grid inertia conditions
- BESS FFR capability to support the WI grid frequency stability for a large generator trip contingency
- The effects of BESS FFR over a typical primary frequency control time frame[33]
- The grid frequency stability with a large penetration of IBRs that operate at maximum available output condition and do not provide under frequency support to the grid
- Different locations for BESS placement and the impact to grid frequency performance
- Dynamic grid frequency performance based on the frequency nadir of monitored buses throughout the model in addition to a calculated median frequency

The study aimed to accomplish the following objectives:

- Determined at what penetration of IBR facilities[34] WI frequency performance would initiate UFLS schemes[35]
- Demonstrate the BESS FFR capabilities and improve frequency performance on an Interconnection-wide grid
- Find the needed BESS capacity for study case to return to the base case's frequency performance[36]
- Determine if the BESS FFR support is location sensitive
- Provide the a few sensitivities to account for BESS technology specific characteristics and their impact to Interconnection-wide performance[37]

Classic Frequency Excursion Recovery

A typical frequency recovery curve after a large generation loss event is shown in **Figure 4.1**.[38] The frequency performance is described in four periods: arrest, rebound, stabilizing, and recovery. Based on **Figure 4.1**, the event starts at time t+0 second and the pre-disturbance frequency Value A is defined as the average frequency prior to time t+0. Point C is the lowest frequency point from t+0 to t+12 seconds, and it is called the frequency nadir. Point B is defined as the average of the frequency between t+20 and t+52 seconds. To better track frequency response, these three points have been identified by the NERC Frequency Working Group as the crucial metrics from any given event. The study team tracked Point C, the nadir, as well as the rate of change of frequency (RoCoF) to qualify the relative frequency response benefits the BESS can provide.

[33] Generally between 0 and 52 seconds
[34] Modeled as nonresponsive to under frequency deviations
[35] This is the study case.
[36] Base case is the original case without changing out frequency supportive synchronous generation with the nonresponsive under frequency IBR facilities.
[37] For instance, fast switching from discharging to charging or conditions where BESS is nearing low SOC.
[38] https://www.nerc.com/comm/OC/Documents/2019%20FRAA%20Report%20Final.pdf

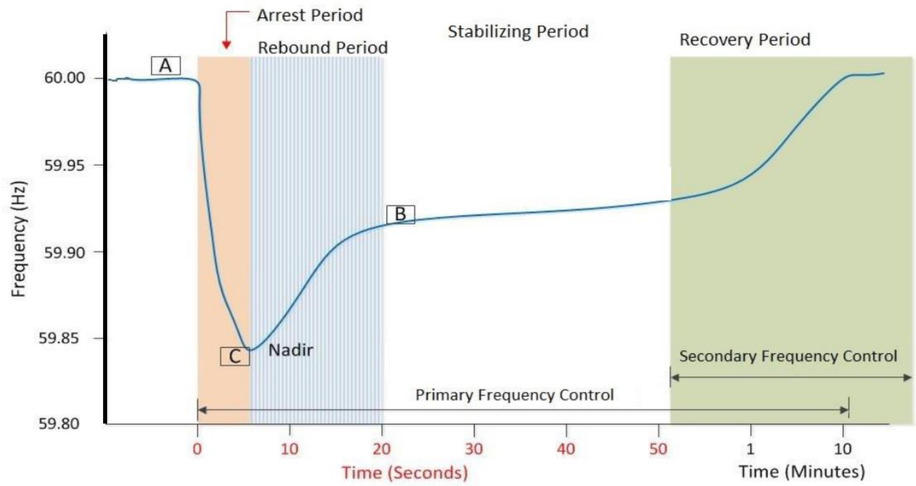


Figure 4.1: Classic Frequency Excursion Recovery

WI Grid Base Case and Study Case Model

To begin, the study team selected the WI 2021 Light Load Spring Planning Case as a starting point.[39] The team captured the WI grid frequency performance subject to a disturbance of the WI's largest N-2 events (two Palo Verde units) based on the NERC recommended resource contingency Criteria.[40] Between the two contingencies, neither reached the first stage of UFLS, hence the study team altered the base case by changing the synchronous generator model with an IBR model that provided no frequency support. There is 8.2% renewable energy power (Wind + PV) output in the base case, and the team altered the penetration to lower the frequency nadir. The team removed 80% of all synchronous generation modeled (based on inertia) in California as well as the top 75 facilities that provided the most PFR to reduce the nadir close to the first stage of UFLS. Compared to the base case, the study case has a reduction of 40% synchronous generator capacity (in MVA) that is replaced by IBRs (with non-frequency-responsive controls), and the corresponding inertia dropped by 34.4%. This altered case is referred to as the "Study Case" in the sections below.[41]

Grid Frequency Response Reserve and BESS FFR

Comparing to the Base Case, the Study Case has a 9.4 GW (26.3%) reduction of spinning reserve and 7.8 GW (23.5%) reduction of frequency response reserve. With the added 1,250 MW BESS[42] to the study case, frequency performance was similar to the Base Case. The different cases basic information related to grid frequency stability are summarized in **Table 4.2**.

Table 4.2: 2021 Light Load Spring Case Summary and Comparison

Quantity	Base Case	Study Case	Study Case + BESS
Total Capacity on Line	119,886 MW	119,886 MW	121,136 MW
Total Case Inertia	604,665 MVA-sec	396,947 MVA-sec	396,947 MVA-sec
Resource MW dispatched	96,312 MW	96,312 MW	96,312 MW
Total Load on the system	92,306 MW	92,306 MW	92,306 MW
Frequency Responsive MW on line	75,294 MW	50,748 MW	51,998 MW
Spinning Reserve (total headroom)	38,041 MW	28,625 MW	29,875 MW

[39] This is due to this case having the lowest inertia of the available cases at time of study. That is, lowest number of synchronous facilities online to provide energy to arrest a frequency decline.
[40] https://www.nerc.com/docs/pc/FRI_Report_10-30-12_Master_w-appendices.pdf
[41] To assist in determining the total IBR penetration differences, the study case has a total or 48.2% IBR penetration and the frequency nadir has 0.05 Hz margin until the first stage of WI UFLS.
[42] This is 12.5% of reduced spinning reserves or 16.67% of frequency response reserves.

Table 4.2: 2021 Light Load Spring Case Summary and Comparison			
Quantity	Base Case	Study Case	Study Case + BESS
Frequency response spinning reserves (frequency response headroom)	31,928 MW	24,112 MW	25,362 MW

BESS Capacity Findings

The team found that by altering the size of the BESS at different locations, it was able to inject power to arrest the frequency nadir. While the location of this injection generally did not matter in relationship to Interconnection-wide grid support, certain local stability problems may be exacerbated or resolved solved by using this BESS capability. It is clear from **Figure 4.2** that the 1,250 MW battery at a droop setting of 1% would bring the frequency support closest to the base case.[43]

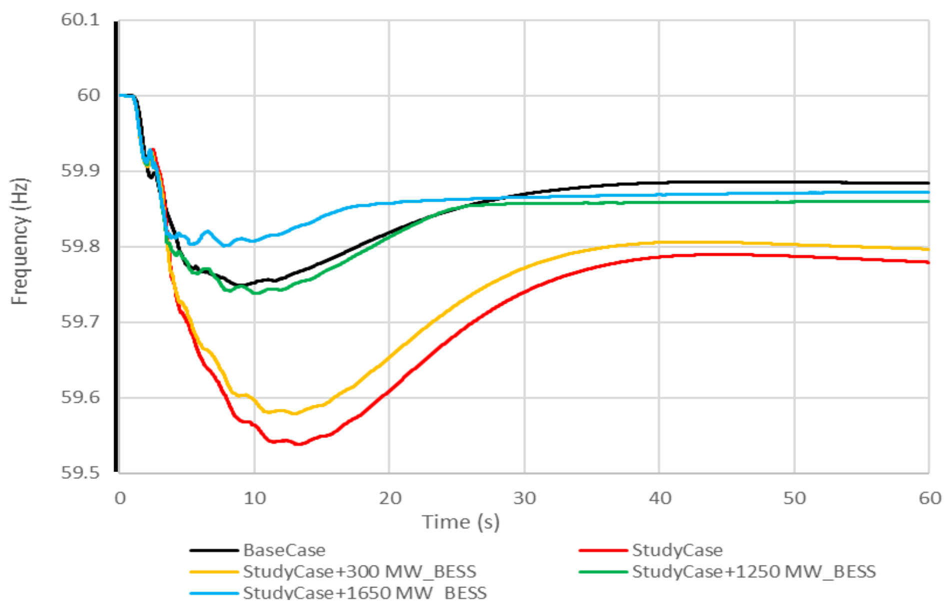


Figure 4.2: Grid Median Frequency for Different BESS Capacity with Two Palo Verde Event

BESS Terminal FFR Performance

As demonstrated in **Figure 4.2**, any amount of BESS would begin to move the Study Case back to the Base Case; however, a closer look at how the BESS performed ought to be determined. In **Figure 4.3**, the BESS active power tracks with the frequency at its terminals, indicating that the FFR capability of the BESS was confirmed. It was able to ramp up to over 100 MW in less than five seconds, which is faster than many other synchronous governor droop responses generators in the WI. As no mechanical delays are needed for this response, BESS are well suited for providing this ancillary service.

[43] This is not, however, a recommendation to require 1% droop.

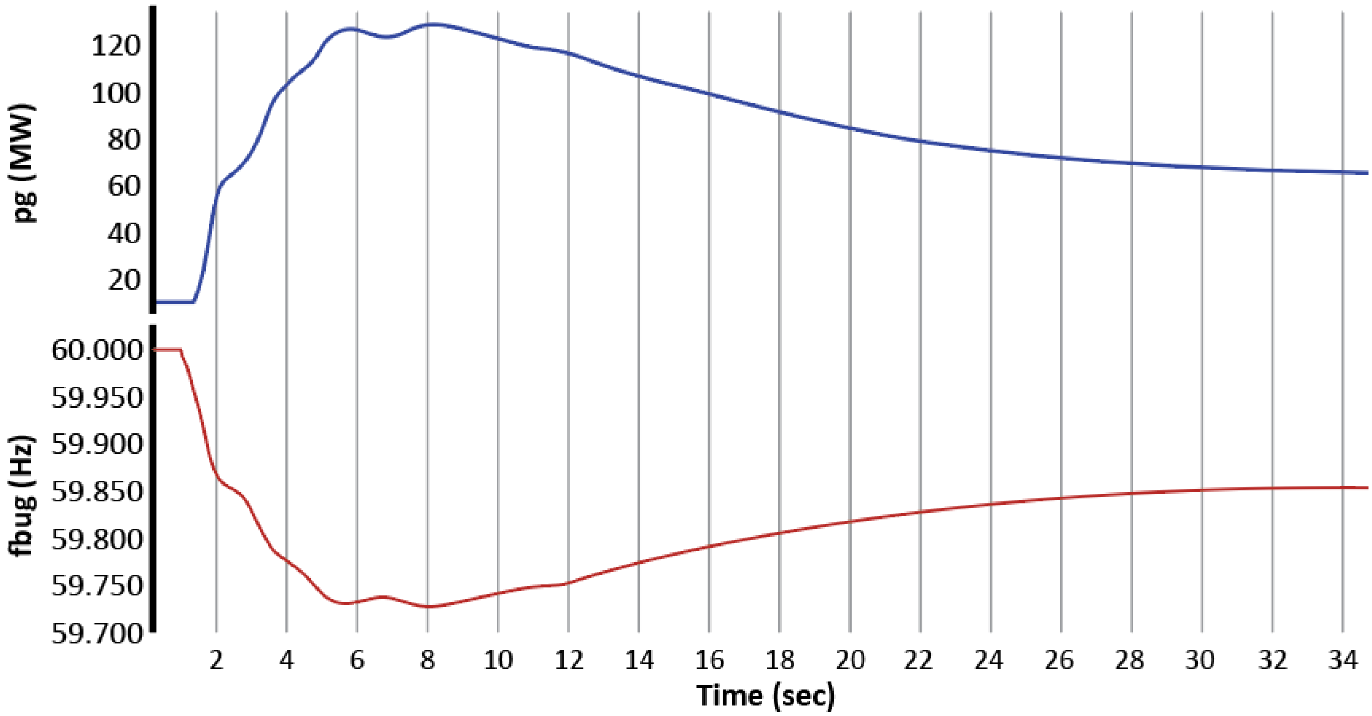


Figure 4.3: BESS Power vs. Frequency Performance

BESS Location Sensitive Findings

To understand how BESS could perform, the study team placed varying sizes at different locations to geographically change where this injection came from. The team found five different locations throughout the WI at strong, well-interconnected locations both near and far away from the contingencies studied, shown in **Figure 4.4**. The selected locations and the rationale behind selection are found in **Table 4.3**.

Table 4.3: Location Selection

Location	Reason
1-Southern Oregon (Malin)	WI highly interconnected transmission bus
2-Southern California (Moss Landing)	Nearby Load center and already identified site for a large BESS
3-Arizona (Palo Verde)	Near location of WI Resource Loss Protection Criteria (RLPC)
4-New Mexico (Four Corners)	Near area of a large synchronous generator that may retire
5-Montana (Colstrip)	Emphasizing weaker grid conditions

The numbers in the **Table 4.3** Location column relate to the areas found in **Figure 4.4**.

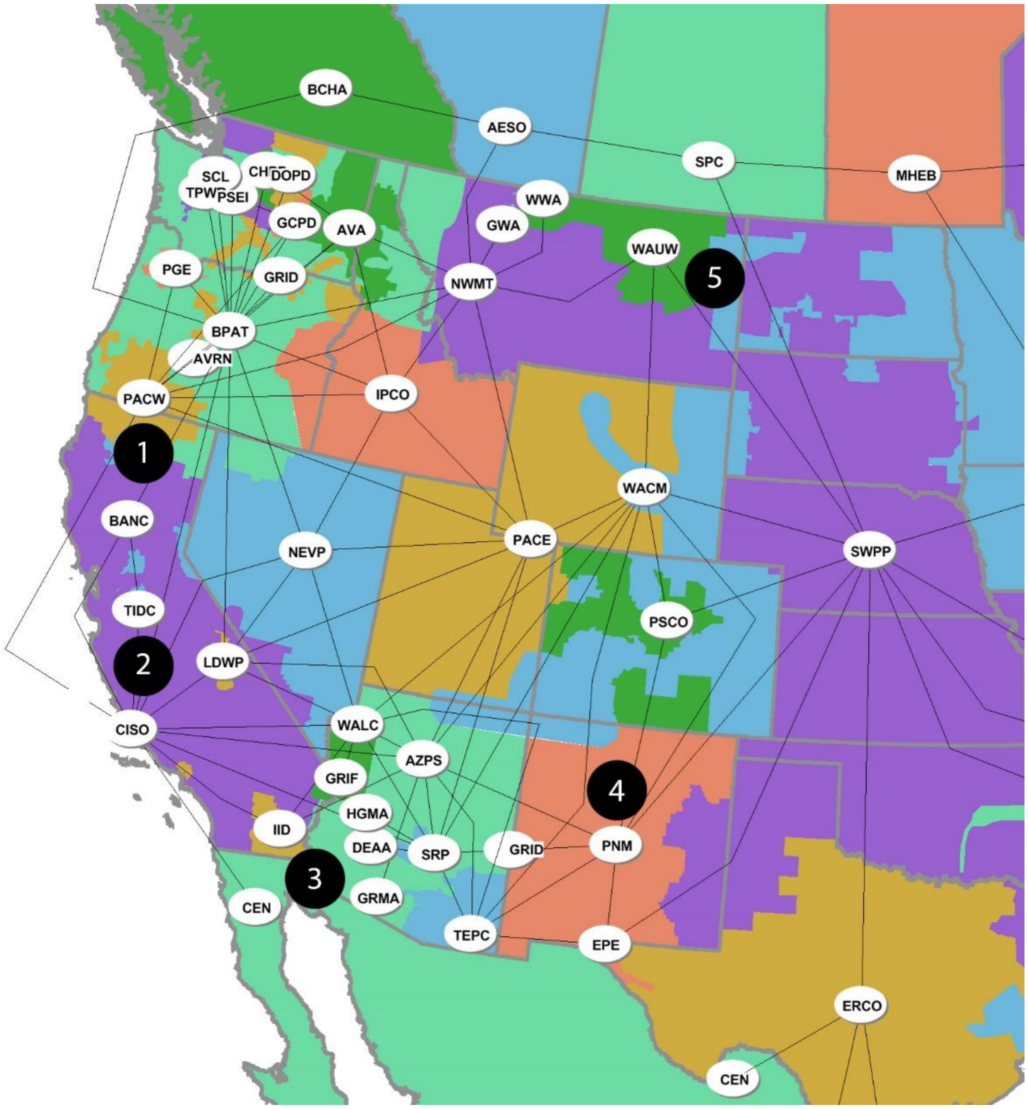


Figure 4.4: BESS Location Selection

The corresponding BESS bus frequency for these locations is displayed in **Figure 4.5**. The Palo Verde bus has the most frequency drop after a disturbance, and the Colstrip bus has the most delayed frequency drop among the selected five locations. The lowest frequency bus is also added in **Figure 4.5**, which occurs at Genesee. As shown in the figure, the first 10 seconds largely show the difference; however, the overall frequency nadir is not largely affected.

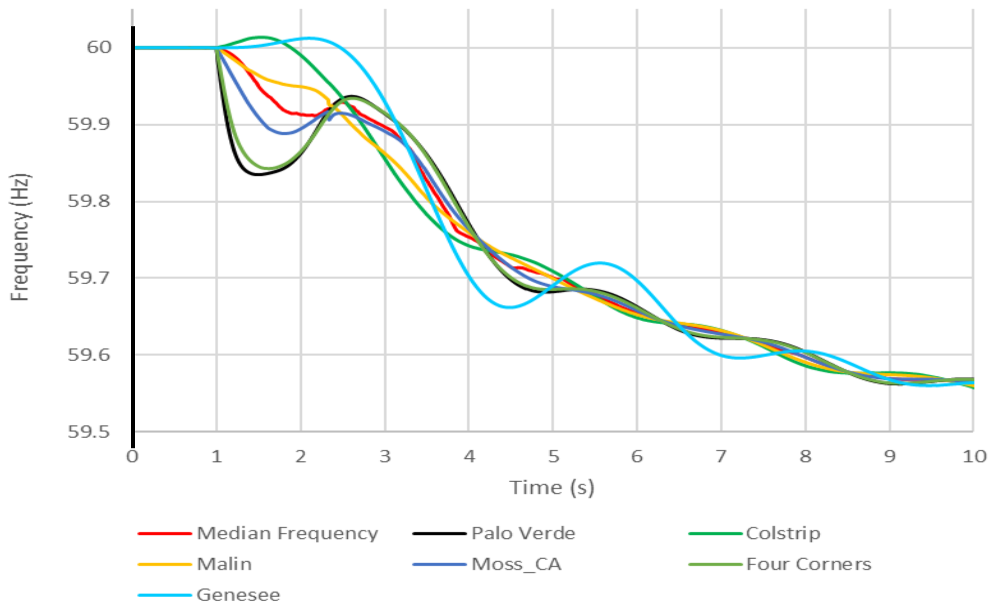


Figure 4.5: Study Case Bus Frequencies for Each BESS Location

Comparison of Aggregated Large BESS and Evenly Distributed Small BESS

For the five selected study locations, the grid frequency response and the BESS FFR contributions are simulated for both the single large BESS and the five smaller BESS. A single 1,250 MW BESS with 1% droop at five locations and the evenly split 250 MW BESS with the same droop at five different Bulk Electric System (BES) BES-connected locations provided similar Interconnection-wide performance. The grid median frequency and the major grid buses frequency are shown in **Figure 4.6**. The BESS FFR power response at five buses are compared in **Figure 4.7**.

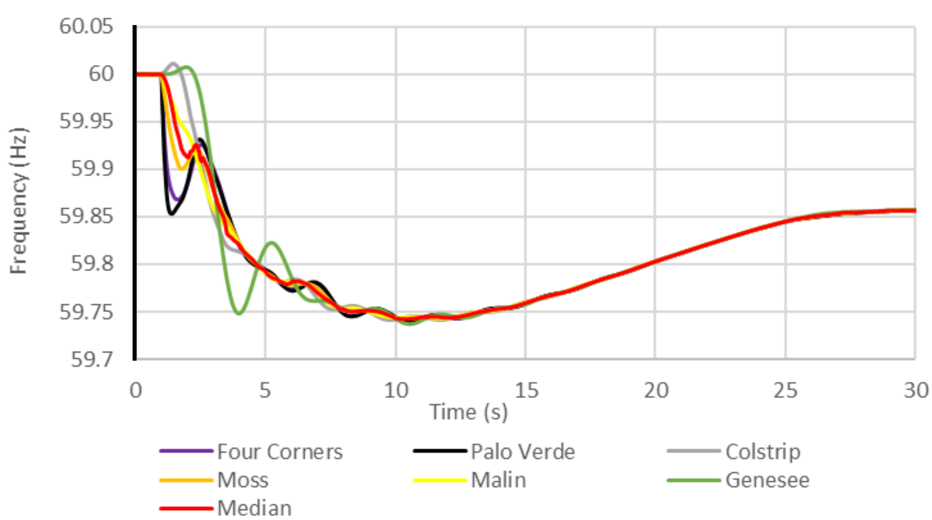


Figure 4.6: BESS Bus Frequencies for Five Small BESS

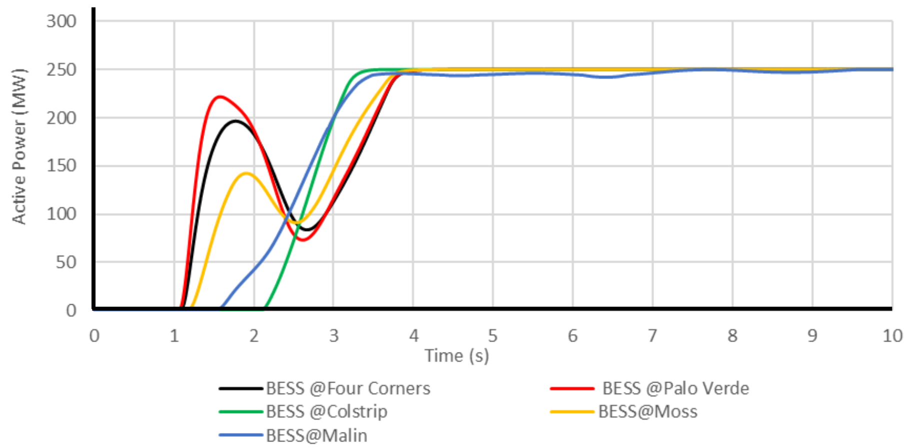


Figure 4.7: Active Power at Each BESS

The BESS power output at each of the five locations for a single 1,250 MW large battery and the sum of 5 x 250 MW evenly distributed BESS are compared in **Figure 4.8**. The red curve is the sum of the five small 250 MW BESS response installed at all five locations. The black curve is for BESS power response when it is at the same Palo Verde location as the tripped generator location. The other five curves are power response for the single large 1,250 MW BESS installed at one location.

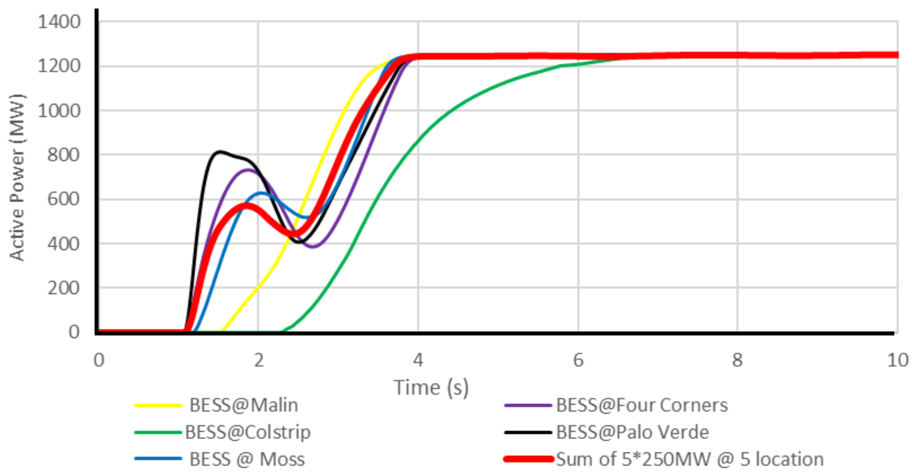


Figure 4.8: BESS Active Power Comparison of Single BESS vs. Many BESS

The aggregation of the 250 MW BESS performed similarly to the single 1,250 MW BESS in arresting the frequency excursion. As expected, the five local BESS active power output summation does not have as exaggerated local conditions due to distributing the BESS across the BES. The active power of the 5–250 MW BESS follows very well with the comparison between each of the single installation of 1,250 MW BESS at different locations with the exception that the delay in the latest response location at Colstrip that was not as well pronounced in reaching the maximum output. In **Figure 4.8**, Colstrip (green curve above) did respond later[44] than the other buses because of the BESS local frequency[45] decreasing later.

[44] One second delay in starting the response and three seconds longer to reach maximum output.

[45] As the droop characteristic of the BESS relies upon a frequency lower than its nominal minus deadband prior to injecting power, the delay in frequency decline is the cause for the delay in active power output for this location.

Grid Median frequency performance

The grid median frequencies between the summated 250 MW BESS and the single 1,250 MW BESS at each location are compared in **Figure 4.9**. For these five locations, 1,250 MW BESS support grid median frequency back to the similar base case grid median frequency performance, which has the nadir at around 59.75 Hz at the 10-second mark, a full 250 MHz above the first stage of UFLS (59.5 Hz). The grid median frequency nadirs for single large BESS at five different locations and five small BESS are similar.

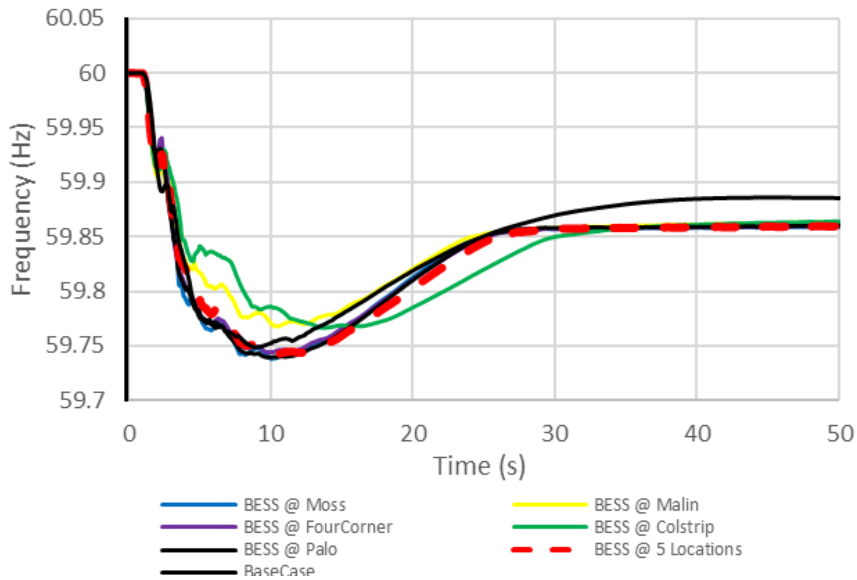


Figure 4.9: Grid Median Frequency Comparison

BESS Sensitivity Findings

The study team wanted to demonstrate the capability of a BESS to change between charging and discharging mode both seamlessly and quickly. As shown in **Figure 4.10**, the Hornsdale Battery did this in 2018, however, the study team wanted to confirm this response along with what may occur if the BESS was not able to contribute to the system due to a lack of charge in the battery packs. This BESS capability can provide the grid with FFR/support for under-over-under frequency events to provide another load shedding protection; this is highlighted in **Figure 4.11**.

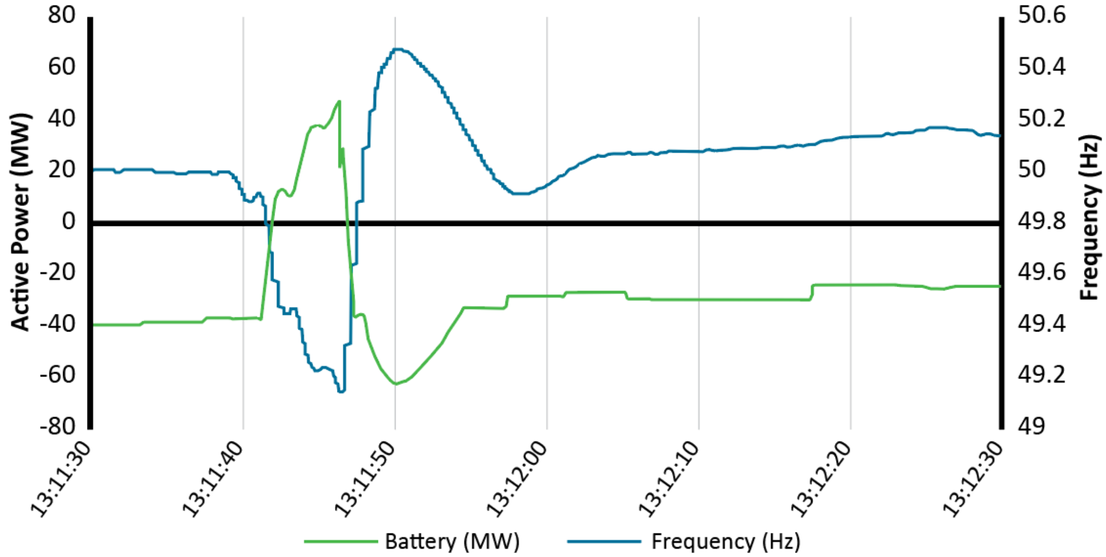


Figure 4.10: Hornsdale Battery Performance Due to the August 25, 2018, Event

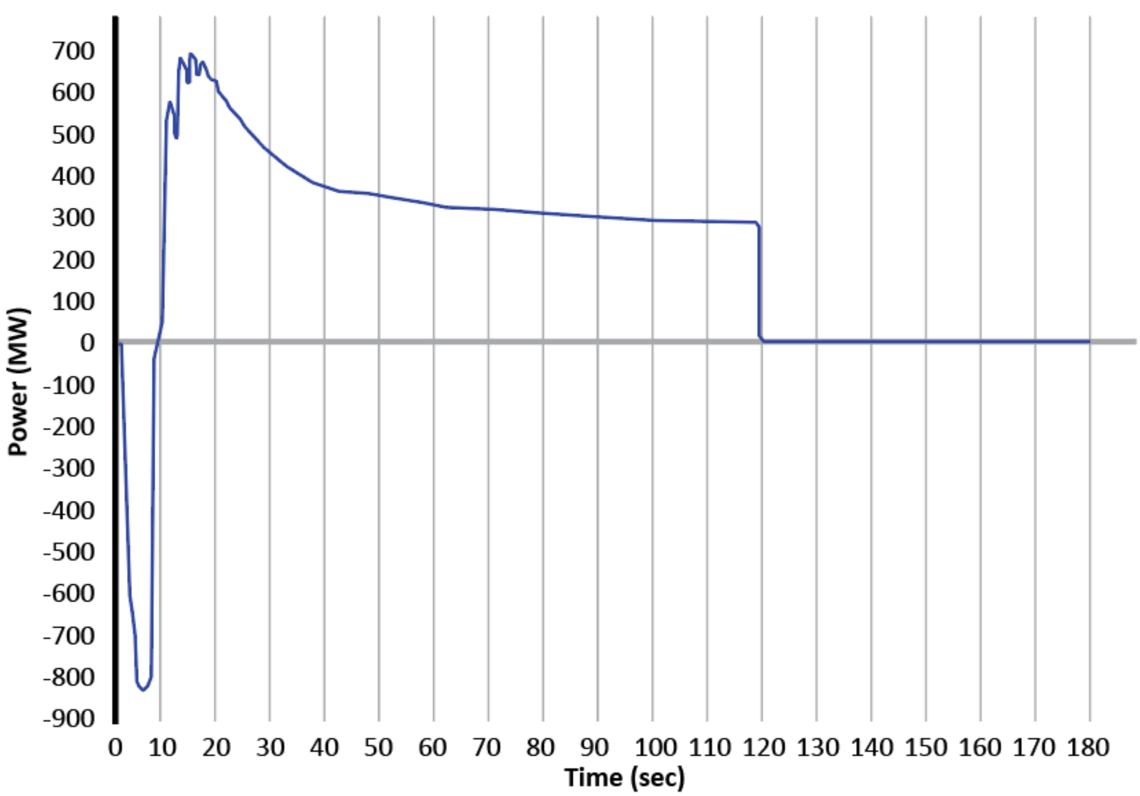


Figure 4.11: BESS Active Power Injection for Three Minutes

As the medain frequency in **Figure 4.11** demonstrates, the BESS was capable of both arresting over and under frequency excursions; however, there is a risk for reliance upon a BESS near the limits of its SOC. While the second frequency decline in **Figure 4.12** is smaller, it does reach a slightly lower nadir. This highlights that, while BESS can support the frequency decline, the BESS will need to be coordinated alongside all other PFR sources to ensure adequate reliabilty prior to secondary or tertiary frequency control.

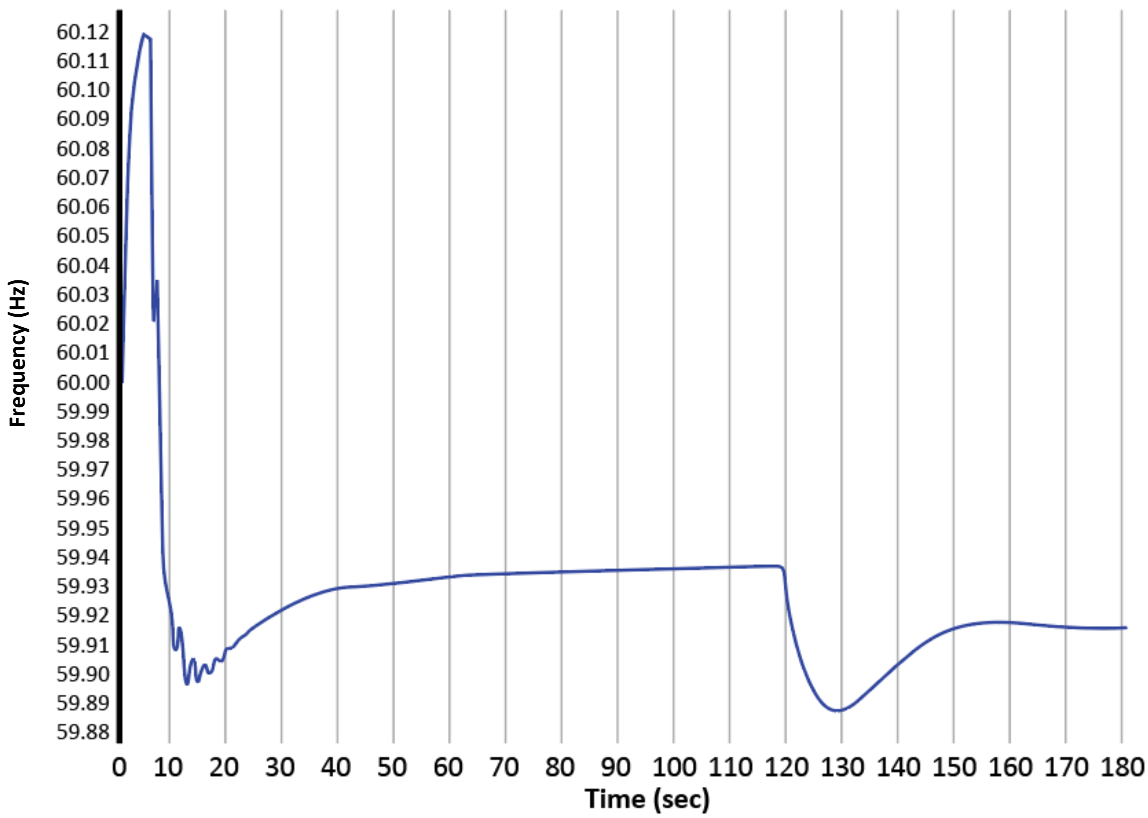


Figure 4.12: Median frequency of the BESS Sensitivity

Conclusion

The study results demonstrate that battery storage can provide sufficient frequency response to support grid frequency stability and improve frequency performance for large generator tripping events and other frequency disturbances for a future high penetration IBR grid with heavily reduced grid inertia. In the study, energy is injected to the grid at high speeds from the BESS at locations to reduce the grid frequency stability risks associated with the decreasing grid inertia, such as high RoCoF immediately following an event. The study also demonstrated that BESS start supporting grid frequency during the arresting period and improve the frequency nadir and overall frequency performance. Some risks associated with such PFR offered by BESS are related to inadequate coordination among other PFR sources and ensuring adequate control stability. Transmission Planners and Planning Coordinators are encouraged to perform future studies in order to understand both the local interconnection constraints and coordination among BESS and other PFR sources to ensure adequate and stable frequency support. As this study is only one facet of a BESS's capabilities, the other benefits of BESS should be considered through continued industry and regional studies. Additionally, policy makers are encouraged to use these studies to understand the impacts of increasing IBRs and how BESSs can be designed to mitigate specific risks.[46]

[46] Conversely, using such studies to understand BESS exacerbations to risks is highly encouraged.

Chapter 5: Battery Storage—NERC and FERC

NERC Standards Applicability

According to Appendix 5B of the NERC Rules of Procedure,[47] NERC and the REs are obligated to identify and register entities that are owners, operators, and users of the BPS and are determined to have a material impact on the BPS. These registered entities are responsible for complying with all relevant and approved NERC Reliability Standards.

NERC Reliability Standards provide for the reliable planning and operation of the BPS across North America and apply to entities that use, own, or operate elements of the BES as established by NERC's approved definition of BES.[48] The BES definition includes all transmission elements operated at 100 kV or higher and real power and reactive power resources connected at 100 kV or higher. Determining whether standalone BESS or those combined with other types of generation (hybrid plants) are subject to NERC jurisdiction requires evaluating them with the BES definition.

Currently, an ERO working group is drafting a document to provide guidance on the application of the BES definition to BESS and hybrid resources and address the related registration issues for the owners and operators of these facilities. When completed, this document will be located in the Registration Documentation section on the Organization Registration and Organization Certification page of NERC.com.[49]

NERC Standards Review

As noted above, NERC Reliability Standards provide for the reliable planning and operation of BPS generation and transmission facilities. Until recently, the generation facilities applicable to NERC Reliability Standards were primarily synchronous machines, but that is no longer the case. More and more, the generation mix includes asynchronous (inverter-based) resources, such as wind, solar PV, and battery facilities. The inverters are the interface between these resources and the electric grid. Therefore, the NERC Reliability Standards must call for performance of inverter-base resources that contributes to the reliable operation of the BES and does not introduce unknown or unstudied risks to the BES. For this reason, the NERC standing committees tasked the NERC Inverter-Based Performance Working Group (IRPWG) with evaluating the current body of NERC Reliability Standards to determine whether the requirements are sufficient as written to address the inclusion of IBR. The IRPWG published a white paper in March 2020[50] that detailed its findings and recommendations. The IRPWG identified potential areas for improvements in seven NERC Reliability Standards and submitted standard authorization requests to the NERC Standards Committee to address the following recommendations[51]:

- FAC-001-3 and FAC-002-2 should be revised to: (a) clarify which entity is responsible for determining which facility changes are materially modifying, and therefore require study, (b) clarify that a Generator Owner should notify the affected entities before making a change that is considered materially modifying, and (c) revise the term "materially modifying" so as to not cause confusion between the FAC standards and the Federal Energy Regulatory Commission (FERC) interconnection process;
- MOD-026-1 and MOD-027-1 should either be revised or a new model verification standard should be developed for IBR since these standards stipulate verification methods and practices, which do not provide model verification for the majority of the parameters within an inverter-based resource. For example, the test currently used to comply with MOD-026-1 does not verify the model parameters associated with voltage control behavior during large disturbance conditions;

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47 https://www.nerc.com/FilingsOrders/us/RuleOfProcedureDL/NERC_ROP_Effective_20190125.pdf

48 https://www.nerc.com/pa/Stand/Pages/2018%20Bulk%20Electric%20System%20Definition%20Reference.aspx

49 https://www.nerc.com/pa/comp/Pages/Registration.aspx

50 https://www.nerc.com/comm/PC/InverterBased%20Resource%20Performance%20Task%20Force%20IRPT/Review_of_NERC_Reliability_Standards_White_Paper.pdf

51 The IRPWG did not identify issues with the existing standard language in the BAL, CIP, COM, EOP, INT, IRO, NUC, PER, TOP, or the remainder of the FAC, MOD, TPL, PRC, and VAR families of NERC Reliability Standards.

- PRC-002-2 should be revised to require disturbance-monitoring equipment in areas not currently contemplated by the existing requirements, specifically in areas with potential inverter-based resource behavior monitoring benefits;
- Clarifications should be made to TPL-001-4 to address terminology throughout the standard that is unclear with regards to IBR the next time the standard is revised. This terminology was not changed in the recently FERC-approved TPL-001-5 version of the standard; and
- VAR-002-4.1 should be revised to clarify that the reporting of a status change of a voltage-controlling device per Requirement R3 is not applicable for an individual generating unit of a dispersed power producing resource, similar to the exemption for Requirement R4.

In February 2018, FERC issued Order No. 841, determining that NERC Reliability Standards are technology neutral and do not create barriers that would inhibit electric storage resources or other nonsynchronous technologies from participating in the RTO/ISO markets. A more comprehensive review of recent FERC orders follows.

FERC Orders Relevant to BESS and Hybrids[52]

FERC recently issued orders pertaining to electric storage resources. FERC defined an electric storage resource as "a resource capable of receiving electric energy from the grid and storing it for later injection of electric energy back to the grid." [53]

FERC's determinations in Order No. 841, Order No. 842, and Order No. 845[54] are leading to new wholesale market participation models, updates to interconnection study processes, and new operating practices.

FERC Order No. 841

In Order No. 841 (February 15, 2018), FERC required Regional Transmission Organizations (RTOs) and Independent System Operators (ISOs) under its jurisdiction to establish participation models that recognize the physical and operational characteristics of electric storage resources. Each participation model, per the order, must "ensure that a resource using the participation model for electric storage resources is eligible to provide all capacity, energy, and ancillary services that it is technically capable of providing in the RTO/ISO markets" and "account for the physical and operational characteristics of electric storage resources through bidding parameters or other means."[55] These ancillary services may include blackstart services, primary frequency response services, reactive power services, frequency regulation, or any other service defined by the RTO/ISO.[56]

FERC gave flexibility to both transmission providers, in determining telemetry requirements as well as to electric storage resources, in managing SOC.[57] To the extent that electric storage resources are providing ancillary services, such as frequency regulation, an electric storage resource managing its SOC is required to follow dispatch signals. For ease of reference, FERC provided a chart of "physical and operational characteristics of electric storage resources for which each RTO's and ISO's participation model for electric storage resources must account," as shown in **Table 5.1**.[58] How these characteristics are accounted for in participation models may vary between RTOs and ISOs. These definitions are not endorsed by NERC; rather, they are provided here as a reference.

[52] Excerpted from the NERC Reliability Guideline "Performance, Modeling, and Simulations of BPS-Connected BESS and Hybrid Power Plants"
[53] FERC Order No. 841, paragraph 29
[54] https://www.ferc.gov/enforcement-legal/legal/major-orders-regulations
[55] FERC Order No. 841, paragraph 4
[56] FERC Order No. 841, paragraph 79
[57] FERC Order No. 841, paragraphs 209 and 246
[58] FERC Order No. 841, paragraph 231

Table 5.1: FERC Participation Model Parameters	
Physical or Operational Characteristic	**Definition**
State of Charge (SOC)	The amount of energy stored in proportion to the limit on the amount of energy that can be stored, typically expressed as a percentage (It represents the forecasted starting SOC for the market interval being offered into.)
Maximum SOC (SOC_{max})	A SOC value that should not be exceeded (i.e., gone above) when a resource using the participation model for electric storage resources is receiving electric energy from the grid (e.g., 95% SOC)
Minimum SOC	A SOC value that should not be exceeded (i.e., gone below) when a resource using the participation model for electric storage resources is injecting electric energy to the grid (e.g., 5% SOC)
Maximum Charge Limit	The maximum MW quantity of electric energy that a resource using the participation model for electric storage resources can receive from the grid
Maximum Discharge Limit	The maximum MW quantity that a resource using the participation model for electric storage resources can inject to the grid
Minimum Charge Time	The shortest duration that a resource using the participation model for electric storage resources is able to be dispatched by the RTO/ISO to receive electric energy from the grid (e.g., one hour)
Maximum Charge Time	The maximum duration that a resource using the participation model for electric storage resources is able to be dispatched by the RTO/ISO to receive electric energy from the grid (e.g., four hours)
Minimum Run* Time	The minimum amount of time that a resource using the participation model for electric storage resources is able to inject electric energy to the grid (e.g., one hour)
Maximum Run Time	The maximum amount of time that a resource using the participation model for electric storage resources is able to inject electric energy to the grid (e.g., four hours)
Minimum Discharge Limit	The minimum MW output level that a resource using the participation model for electric storage resources can inject onto the grid
Minimum Charge Limit	The minimum MW level that a resource using the participation model for electric storage resources can receive from the grid
Discharge Ramp Rate	The speed at which a resource using the participation model for electric storage resources can move from zero output to its maximum discharge limit
Charge Ramp Rate	The speed at which a resource using the participation model for electric storage resources can move from zero output to its maximum charge limit

* Note that the definitions here interchange “run” and “discharge.” The preferred term is “discharge.”

FERC Order No. 842

In Order No. 842 (February 15, 2018), FERC (the Commission) determined that electric storage resources under its jurisdiction are only required to provide PFR when they are "online and are dispatched to inject electricity to the grid and/or dispatched to receive electricity from the grid."[59] This excludes situations when an electric storage resource is not dispatched to inject or receive electricity.[60] FERC required electric storage resources and transmission providers to specify an "operating range for the basis of the provision of primary frequency response."[61] The operating range, FERC explained, represents the minimum and maximum states of charge between which an electric storage resource must provide PFR. The operating range for each electric storage resource must exhibit the following:

- Be agreed to by the interconnection customer and the transmission provider and in consultation with the balancing authority
- Consider the system needs for primary frequency response
- Consider the physical limitations of the electric storage resource as identified by the developer and any relevant manufacturer specifications
- Be established in Appendix C of the *Large Generator Interconnection Agreement* (LGIA) or Attachment 5 of the *Small Generator Interconnection Agreement* (SGIA)[62]

The Commission noted that this suite of requirements "effectively allows electric storage resources to identify a minimum and maximum set point below and above which they will not be obligated to provide primary frequency response comparable to synchronous generation."[63] In summary, the Commission provided electric storage resource interconnection customers with the ability to propose an operating range and the transmission provider or BA the ability to consider system needs for PFRs before determining final operating ranges.

Given that "system conditions and contingency planning can change" and that "capabilities of electric storage resources to provide primary frequency response may change due to degradation, repowering, or changes in service obligations," the Commission determined that the ultimate operating ranges may be dynamic values.[64] If a dynamic range is implemented, then transmission providers must also determine the periodicity of re-evaluation and the factors that will be considered during re-evaluation of the operating ranges. The Commission provided electric storage resources specific exemptions from the PFR provision for a "physical energy limitation," described as follows:

> "…the circumstance when a resource would not have the physical ability, due to insufficient remaining charge for an electric storage resource or insufficient remaining fuel for a generating facility to satisfy its timely and sustained primary frequency response service obligation, as dictated by the magnitude of the frequency deviation and the droop parameter of the governor or equivalent controls."[65]

The Commission also clarified that MW droop response is derived from nameplate capacity.[66] If dispatched to charge during an abnormal frequency deviation, the Commission required electric storage resources to meet PFR

[59] FERC Order No. 842, paragraph 183

[60] As in, electric storage resources are not obligated to provide any frequency response to the BPS if dispatched at zero MW output. However, the requirements in Order No. 842 are minimum requirements and an electric storage resource may provide this service if the market rules or interconnection requirements are set up to enable this capability. Providing primary frequency response when dispatched at zero MW could help BPS frequency stability moving forward.

[61] FERC Order No. 842, paragraph 180

[62] Ibid

[63] Ibid

[64] FERC Order No. 842, paragraph 182

[65] FERC Order No. 842, paragraph 185

[66] For example, for a 5% droop characteristic would equate to a 100% change in power output (based on nameplate capacity) for a 5% change in frequency.

requirements by increasing (for over-frequency) or decreasing (for under-frequency) the "rate at which they are charging according to the droop parameter."[67] To illustrate, the Commission gave an example of an electric storage resource charging at two MW with a calculated response per the droop parameter to increase real-power output by one MW. According to the Commission, during an under-frequency deviation, the electric storage resource could "satisfy its obligation by reducing its consumption by one MW (instead of completely reducing its consumption by the full two MW and then discharging at one MW, which would result in a net of three MW provided as primary frequency response)."[68] Electric storage resources are not required to change from charging to discharging, or vice versa, if technically incapable of doing so during the event when PFR is needed.

The Commission also noted that requirements adopted in Order No. 842 are minimum requirements. An electric storage resource may elect, in coordination with its transmission provider and BA, "to operate in a more responsive mode by using lower droop or tighter deadband settings."[69]

As with all frequency-responsive resources connected to the BPS, the speed of response has a significant impact on frequency performance during large disturbances, particularly in low inertia systems with a high RoCoF. FERC Order No. 842 does not require any speed of response characteristics for electric storage resources.

FERC Order No. 845

In Order No. 845 (April 19, 2018), the Commission clarified that "in certain situations, electric storage resources can function as a generating facility, a transmission asset, or both."[70] The Commission made clear that electric storage resources under its jurisdiction greater than 20 MW had the option to interconnect pursuant to the *Large Generator Interconnection Procedures* (LGIP) and *Large Generator Interconnection Agreement* (LGIA), *"*so long as they meet the threshold requirements as stated in those documents."[71] In the event that the LGIA does not accommodate for the load characteristics of electric storage resources, transmission providers may enter into non-conforming LGIAs.[72]

Furthermore, in Order No. 845, the Commission declined to move forward with "any requirements for modeling electric storage resources":

> "…given the limited experience interconnecting electric storage resources and the abundant desire for regional flexibility, we are not imposing any standard requirements at this time and instead continue to allow transmission providers to model electric storage resources in ways that are most appropriate in their respective regions." [73]

Instead, the Commission encouraged transmission providers to continue to consider modeling approaches that will "save costs and improve the efficiency of the interconnection process."[74]

[67] FERC Order No. 842, paragraph 187
[68] Ibid
[69]FERC Order No. 842, paragraph 188
[70] FERC Order No. 845, paragraph 278. Citing *Western Grid Dev., LLC,* 130 FERC ¶ 61,056 *(Western Grid), reh'g denied*, 133 FERC ¶ 61,029 (2010) and *Utilization of Electric Storage Resources for Multiple Services When Receiving Cost-Based Rate Recovery,* 158 FERC ¶ 61,051
[71] FERC Order No. 845, paragraph 279
[72] FERC Order No. 845, paragraph 285
[73] FERC Order No. 845, paragraph 544
[74] Ibid

Chapter 6: Reference Studies

Summary of Existing Assessments

With the significant increase in BESS, industry and the DOE National Laboratories have conducted a number of relevant studies. A high-level summary of some of those relevant studies and reports are detailed below. The information provides considerations for the increasing deployment of BESS as well as the roles BESS have played in BPS events.

Technical Papers

Lawrence Berkeley

Drivers of the Resource Adequacy Contribution of Solar and Storage for Florida Municipal Utilities[75]

The Lawrence Berkeley National Laboratory published this report to explore how solar PV coupled with BESS will aid solar PV in achieving a higher resource adequacy contribution. A case study performed in Florida looked into the primary drivers for an estimation of resource adequacy contribution. The report shows the importance of hybrid BESS and their contributions to resource adequacy contributions in assisting IBRs. BESS can reduce an IBR's variability by adding more electrical generation when the electrical generation of the IBR is lower.

Capacity credit decreases as the penetration of solar resources increases. Lawrence Berkeley states that, to reach a higher level of capacity credit, storage requires longer hours of production at full output. Storage is required to serve a significant portion of the peak demand to assist the IBRs in achieving the higher resource adequacy contribution.

Sandia

Small Signal Stability of the Western North American Power Grid with High Penetrations of Renewable Generation[76]

Sandia published a report that assessed the effect of high penetration solar deployment on the small signal stability of the western North American power system. "Small Signal Stability" refers to a system's ability to stay stable subject to small perturbations in system load, generation, and other system conditions, such as voltage and frequency. By doing so, they created a situation where the balancing of the generation and load required other converter based generation resources to provide for their reserves. They added BESS to account for additional reserve requirements in their study in order to meet specific reserve requirements and distributed them throughout each of their two cases. The two cases in question were a 2022 light spring and 2016 heavy summer case modified to look closely at the eastern portion of the WI. With a focus on inter-area oscillation control and mitigation from the BESS, the study team concluded that "as converter-based renewable sources become more prevalent, the characteristics of inter-area oscillations will likely change." As the amount of renewable generation increased, the two WI North–South modes increased in frequency while the damping remained relatively constant with the distributed BESS controllers implemented. Batteries under proper control schemes have capabilities to dampen down power oscillations if they are designed and compensated for those services. They can use these characteristics to play a role in increasing the damping effect of inter-area, plant level, and other types of oscillatory events on the power system. Batteries can assist in reducing the oscillations as more solar PV and wind resources come online and plays a key role in addressing some of the operational risk associated with the changing resource risk.

[75] Drivers of the Resource Adequacy Contribution of Solar and Storage for Florida Municipal Utilities

[76] Small Signal Stability of the Western North American Power Grid with High Penetrations of Renewable Generation

National Renewable Energy Laboratory

Sunny with a Chance of Curtailment: Operating the U.S. Grid with Very High Levels of Solar Photovoltaics[77]

The National Renewable Energy Laboratory (NREL) authored this article published in the iScience journal that discussed a future power system with high levels of solar PV generation. As many areas of the NERC footprint continue to develop higher levels of solar PV and wind, we need to understand how the BPS will operate in order to effectively preserve BPS resiliency and reliability**.** An extreme case presents 55% of the 2050 annual electricity generated by solar PV. The study concludes solar PV can serve 90% of peak demand if the system can offset high levels of curtailment with massive amounts of energy storage. NREL identifies larger ramps, high instantaneous PV penetration, routine curtailments, and the increased frequency of low and zero energy prices as considerations for a largely solar PV generated power system. BESS aid to mitigate larger ramps by providing quick-start generation that is dispatchable in varying quantities. Curtailments of the solar PV and wind resources will be reduced as the BESS will charge using the generation normally lost to curtailments. The increased frequency of low and zero energy prices will further encourage battery storage as arbitrage pricing will incentivize the batteries to use these situations to charge up at little to no cost. Preserving the reliability and resiliency of the BPS with a future of high levels of IBR generation requires BESS to be available in large quantities. BESS help to address the aforementioned larger ramps, high instantaneous PV penetration, and routine curtailments. Battery storage becomes an increasingly vital part of the generation fleet as the penetration of IBRs continues to increase.

Pacific Northwest National Laboratory

Snohomish Public Utility District MESA-1: An Assessment of Battery Technical Performance[78]

PNNL provided a comprehensive BESS technical test on the attributes providing benefits to stakeholders, utilities on a battery project located at the Hardeson Substation in Everett, Washington. Detailed BESS technical capabilities are tested, such as stored energy capacity, fast ramp rate performance, the ability to track variable charge/discharge commands for fast/primary frequency response primary, and time shifting of renewable energy. At the same time, BESS arbitrage and power factor correction functions are also examined for BESS performance while engaged in specific economic services. A number of technical lessens are learned from the test results, the test design setup/data transfer, test disruptions, and investigations that would be beneficial for any task or effort that needs BESS technical assessment based on field deployment results.

Planning Considerations for Energy Storage in Resilience Applications: Outcomes from the NELHA Energy Storage Conference's Policy and Regulatory Workshop[79]

PNNL summarized BESS resilience applications from the Natural Energy Laboratory of Hawaii Authority Conference's Policy and Regulatory Workshop. BESS are a key enabling technology in resilience applications and the BESS role in grid resilience services is discussed in bulk energy services, ancillary services, transmission/distribution services, and customer services.

System Recovery Aided by BESS

- OFGEM (Office of Gas and Electricity Markets) Great Britain Blackout
- August 9, 2019, Power Outage Report[80]

[77] Sunny with a Chance of Curtailment: Operating the USU.S. Grid with Very High Levels of Solar Photovoltaics
[78] https://energystorage.pnnl.gov/pdf/PNNL-27237.pdf
[79] https://energystorage.pnnl.gov/pdf/PNNL-29738.pdf
[80] 9 August 2019 Power Outage Report

OFGEM is part of Great Britain's government and is responsible for the interests of existing and future electricity and natural gas consumers. On August 9, 2019, over one million customers lost power in Great Britain. Disruptions included trains in and around London along with outages in and around the city. BESS assisted with dampening the impact of the blackout by temporarily supporting frequency drops. The series of events are detailed below, highlighting the role batteries played.

Great Britain was operating with 10 GW of wind resources, or about 30% of its available capacity. A lightning strike on a 400 kV line resulted in the tripping of 150 MW of generation. At the same moment, a 737 MW offshore wind farm and 244 MW natural-gas-fired steam turbine tripped off-line. These two units tripped independent of each other, but coincident with the lightning strike. The report states, "As this generation would not be expected to trip off or de-load in response to a lightning strike, this represents and extremely rare and unexpected event." The aforementioned events caused a power loss greater than the 1 GW threshold specified by the national grid's security standards. The Security standard limits for tripped generation were exceeded, causing the RoCoF protections systems to enact. The National Grid footprint is designed to operate at 50 Hz. The RoCoF protection system lead to an additional 350 MW of generation to trip off-line, causing the system frequency to reach 49.1 Hz. The report highlighted that 1,481 MW of generation has been lost up to this point and that the reserves were exhausted. As the system was recovering from the previous events, another 210 MW unexpectedly tripped off-line, bringing the cumulative losses to 1,691 MW. Since the reserves were exhausted, the frequency fell to 48.8 Hz. The UK system's low frequency demand disconnection responded to the frequency drop and disconnected demand at its designed 48.8 Hz limit. The low frequency demand disconnection removed 1.1 million customers, totaling 1 GW of load shed.

BESS provided for 200 MW of standby response during the event. BESS were instrumental in a system recovery of less than four minutes, four times faster than an event a decade before. The batteries also played a role in stabilizing frequency following the load shed. The batteries consumed energy to balance the sudden jump in frequency when customers were disconnected. It is hypothesized that with the addition of more BESS, the event could have been subdued before demand was disconnected. Batteries play the role of operating reserves and are readily available generation at a moment's notice.

AEMO (Australia Blackout)

Final Report – Queensland and South Australia system separation on August 25, 2018.[81]

The Australian Energy Market Operator (AEMO) published this report to detail the events of the August 25, 2018, blackout. Detailed analysis includes insights for the cause of the event and the response of the system in mitigating adverse effects. Similar to the OFGEM's conclusions, results from the report explain how a lack of primary frequency control played a role in the blackout. Transmission-connected batteries played a role in stabilizing the grid post blackout by assisting in the recovery of the power system's frequency. The BESS initially served a generating role to raise the frequency and then switched to a load role when over-frequency conditions occurred during the recovery process. In the event of a system blackout, the dual function of batteries to act as a generator or load is valuable.

The AEMO system first experienced disturbances at 1:11:39 p.m., when two 330 kV lines faulted. The lines subsequently tripped seconds later, causing a separation between Queensland and New South Wales. Another 330 kV line tripped, causing the automatic adaptive UFLS-2 scheme to activate. The automatic adaptive UFLS-2 scheme called for 81 MW of industrial load to trip, leading to the separation of South Australia and Victoria. In less than a second, automatic UFLS schemes proceeded to trip almost 1,000 MW of generation. The generating units gradually received permission to restore load, and the New South Wales system fully recovered at 3:28 p.m. A lightning strike to a tower or an earth wire of the tower caused the event. The strike led to large amplitude and steep voltages on the tower.

[81] Final Report – Queensland and South Australia system separation on 25 August 2018

The AEMO system runs at a designed frequency of 50 Hz. Frequency changes that occur beyond a certain rate trigger the emergency RoCoF systems to enact, creating a loss of generation. Batteries support the changes in frequency during an event to dampen the dramatic changes of frequency during system failure and recovery. As with the National Grid event, BESS assume the role of a generator when there is under-frequency and the role of load when there is over-frequency. Primary frequency control is one of the functions utility-scale BESS provides.

Chapter 7: Conclusion

Over the last few years, battery energy storage has grown significantly across North America. In 2014, utility-scale battery storage capacity in North America was approximately 214 MWs. By 2019, this amount increased to 899 MWs. This growth is expected to continue with utility scale storage levels reaching 3,500 MWs by 2023. Key drivers of this growth include the decrease in technological costs as well as market rules that continue to promote the ability of battery storage to offer services in organized markets.

IBR, such as wind and solar, also continue to grow. This provides, an opportunity for BESS to complement renewable projects in the form of hybrid facilities. Additionally, BESS has the capability to provide ERS to the BPS, such as voltage support, frequency response, and ramping. Therefore, BESS can contribute to the reliable operation of the BPS in a similar fashion as synchronous resources that provide those same necessary characteristics to the grid. With other NERC REs, system planners should conduct further analysis to model a system with significant battery storage and hybrid power plants.

A joint NERC/WECC study determined that BESS located in strategic areas can provide effective FFR to avert UFLS. Similarly, studies have concluded that BESS were used to provide FFR helped the United Kingdom and Australia systems avoid larger disturbances in recent frequency excursions. As BESS becomes a larger share of the resource mix, it will be important to conduct more studies to assess the ability to contribute to ERS and provide necessary grid support.

While the resources and technologies used to power the electric system are changing, the principles required to protect and maintain the reliability of the grid and codified in NERC Reliability Standards remain constant. However, as discussed in **Chapter 5**, the evolving grid will require occasional revisions to NERC Reliability Standards to address specific issues or provide additional clarity. In these instances, the NERC Reliability Standards will be modified in accordance with the NERC Standards Development Process.[82]

[82] SPM: https://www.nerc.com/comm/SC/Documents/Appendix_3A_StandardsProcessesManual.pdf

Appendix A: Contributions

NERC would like to express its appreciation to the many people who provided technical support and identified areas for improvement as well as all the people across the industry who work tirelessly to keep the lights on each and every day.

Name	Title
RSTC	
William D. Shultz	Southern Company, Engineering Manager
José A. Marrero	Southern Company, Principal Engineer
Mark Ahlstrom	NextEra
Clyde Loutan	California ISO
Deepak Ramasubramanian	Electric Power Research Institute
Brian Evans-Mongeon	Utility Services Group
Kent Bolton	Sr. Staff Engineer, System Stability Planning
Enoch Davies	Manager, System Stability Planning
Terry Campbell	Manager and Editor, Technical Publications
Alex Carlson	Senior Technical Publications Specialist
Thomas Coleman	Chief Technical Advisor
Stephen Coterillo	Engineer, Reliability Assessment
Hongtao Ma	Senior Engineer, Advanced System Analytics, Modeling & Security
Mani Mardhekar	Senior Engineer, Bulk Power Situational Awareness
Al McMeekin	Senior Technical Advisor, Power Risk Issues and Strategic Management
Levetra Pitts	Senior Program Specialist, Engineering & Standards
Elsa Prince	Principal Technical Advisor, Power Risk Issues and Strategic Management
John Skeath	Engineer II, Advanced System Analytics, Modeling & Security
David Till	Senior Manager, Advanced System Analytics, Modeling & Security
Olushola Lutalo	Lead Engineer, Advanced System Analytics, Modeling & Security