ENERGY STORAGE

A NONTECHNICAL GUIDE

2ND EDITION

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PB
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BOOKS

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ENERGY STORAGE AND THE POWER GRID

Energy storage is proving to be a key component in the power grid. The power grid is built around a central tenet: electricity is produced when it is needed and used once it is produced. This rule necessitates rigid procedures for operating the system in a reliable manner, adding redundancy and efficiency to ensure a stable and high-quality supply of power. Dispatchable power sources (thermal units) have the ability to modify their output to match the changes in demand, but many times the ramp rate needed puts thermal stress on the units, shortening their lifespans. Non-dispatchable sources of power do add some instability to the supply balance, but this impact drops rapidly as the size of the power grid increases and the geographical disbursement of these resources causes them to counteract each other. On the demand side of the equations, increasing customer demand for higher-quality power and faster-changing demand continues to be a growing driver for the power grid to add increasing costs for additional sources of stability for power management. Energy storage systems are poised to help support both sides of this balancing act.

The core strength of energy storage systems is the ability to decouple the linkage between power production and power demand. This capability allows the grid to use storage technologies as both a sink and a source of energy—with the value of these actions increasing with how dynamic the environment is. As a sink, storage facilities can not only absorb energy slowly from generators to optimize their operations, but also absorb rapid surges, preventing imbalances that can affect the power grid's stability. As sources of energy, storage technologies not only can be used to arbitrage energy between off- and on-peak usage, but they can also be used to adjust the rate of energy production and purchases. The ability to affect the supply/demand balance of energy delivered to customers provides the capability to then reduce ramping stress or otherwise optimize the use of generation and transmission assets, or to prevent consumer equipment damage in the retail market from power fluctuations.

The capability of independently storing or releasing energy gives energy storage systems the ability to perform a variety of useful market applications. A critical understanding is that the capabilities must correspond to actual needs by market

Storage Module

The Storage Module (SM) is the most basic component, typically an assembly of energy storage medium assemblies (e.g., battery cells) built into a modular unit to construct the energy storage capacity (kWh) of an energy storage system.

For a lithium-ion system, for example, it would be the complete rack (or tower, or cabinet), consisting of the battery modules, Battery Management System (BMS), and the rack and associated electrical cabling. Most cell-based energy storage technologies will have a similar unit block but may have different cost structures for each sub-component; for instance, lead acid battery systems do not require a BMS system as sophisticated as that of a lithium-ion system. Storage modules are typically priced in $/kWh.

There are a number of areas of concern in the forward price trend for lithium battery systems, which represent the largest source of deployable resources and will be the main focus of this discussion. Some of the major issues of concern include the material cost, manufacturing availability, and competing pressure from other markets (vehicles) for lithium battery cells. Material costs for lithium battery systems have ranged wildly for the last few years and are expected to remain volatile over the near term. The continued disruption of the global supply chain for many industrial materials will also continue to impact the lithium battery manufacturing industry in a variety of ways, including impacting the availability of systems for deployment. This type of situation can exacerbate costs for small purchases in a negative and non-linear manner, as compared to larger buyers. However, as the industry's scale expands, the declining price trend is expected to resume.

Balance of System

The Balance of System (BOS) is the equipment needed to combine a series of storage modules into a complete DC level system. This will include electrical cabling, switchgear, thermal management, and fire suppression, plus the enclosure, ranging from a special purpose enclosure, standard container, or a building.

For many non-cell-based systems, this component is incorporated by OEMs into their smallest commonly provided unit (see the following section for the Battery Energy Storage System (BESS). For instance, flow batteries will include the cost of pumps and other auxiliary Heating, Ventilation, and Air Conditioning (HVAC) systems and electrical protection equipment into their most basic building block. Some cell-based systems with extensive module packaging, such as sodium and zinc-based systems, will also incorporate the storage modules and balance of systems into their basic offering. BOS costs are typically priced in $/kWh.

Overall, the BOS costs have recently risen, with efforts made to address this, causing a wider price range for this equipment recently. The availability of containers (steel) and other BOS equipment such as HVAC, but also racks, cabling, safety equipment, etc., have caused increases in costs and significant delays in replenishment strategy—a plan that takes into account the need to replenish the battery capacity of the facility as required. This is important in order to engage in contracted off-take arrangements, merchant front-of-the-meter operations, or even cost-saving behind-the-meter operations. Different energy storage technologies experience varying degrees of degradation.

Replenishment strategies attempt to find the least costly (and risky) approach to obtain the required capability of the system over its lifespan. The challenge is to map the declining capability of the batteries with the expected usage profile over time to determine how much additional storage capacity must be added, and when. Since the energy rating of a cell-based battery system is expected to decline over time, installing only that which is needed now incurs the least cost for the batteries, but incurs other balance of system costs.

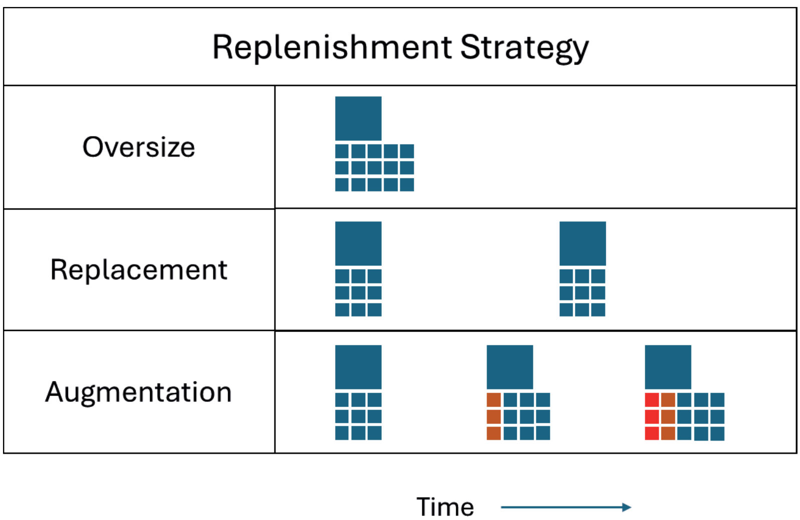

Figure 2.3. Replenishment Strategy[4]

Due to the declining cost of the battery modules, the typical cost-minimization strategy is to only incorporate enough capacity to ensure compliance with the required amount. This strategy thus pushes off into the future as much of the replenishment as possible, as future batteries are expected to cost less. Determining the lowest-cost replenishment schedule will continue to vex many project developers who desire to use the energy storage facility for a number of applications, as many times, developers underestimate the impact on battery life that the actual usage and environmental conditions will have on the system.

Depending on the degree of degradation and the expected usage profile for the facility, different replenishment strategies can be followed to maintain the desired

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SYSTEM DESIGN AND PERFORMANCE

Energy storage systems are not simply reversible energy sinks; they are a highly engineered system with the innate ability to be the most flexible and valuable asset on the power grid. Their great ability to undertake so many market roles comes with the challenge of understanding what the best applications are for a particular energy storage technology to craft an economical valuable system.

The key to unlocking their value is understanding their performance. The answer to that lies in understanding why performance matters to energy storage systems, understanding what performance metrics mean, and how they can be leveraged to obtain lower-cost lending to drive more project development.

Why Performance Matters

Successful project development is based on managing risks. Typically, this means incorporating all the known risks and managing the project's costs and revenues to generate a project with an acceptable IRR. Skill (or luck) is required to also incorporate the ability to manage unknown risks. Understanding the performance of the overall system is crucial to managing the cost-effectiveness of different solutions to manage the project's risks. In this way, a clearer understanding of the risk-adjusted profit potential of the system can be established and of how operational choices affect the ability of the system to maintain profitability over the unit's operating life.

Understanding Performance

Understanding performance is at the heart of performance management, which states that you have to be able to measure something before you can monitor it and monitor it before you can manage it. Energy storage systems are able to perform a variety of tasks under an even wider set of market conditions. Only by understanding the equipment's performance capability can you understand the system's potential; without understanding how to leverage that potential, you can't understand the value of an energy storage system.

the cost to inspect the units. It also provides an opportunity to gather data for predictive maintenance, as the body of operating experience grows. Operation and maintenance concerns have grown with the push toward longer-lived systems, driving a focus on the operation of the facility over time, rather than maintenance of the initially installed equipment, in hopes that it will operate its whole life without incident.

Another driver in cost variation is the type of energy storage technology. Chemical batteries such as lithium-ion systems are typically low-maintenance-cost technology as compared to others with moving parts that require more frequent maintenance. On average, higher usage of the system will require more maintenance for all technologies. In addition, those technologies without significant field operating experience will have more of an open question as O&M needs to maintain expected performance levels for a wide variety of applications, especially when operating in multiple modes simultaneously.

Typical maintenance costs are contracted for a specific annual dollar value per year, although the range can vary widely depending on the level of reliability desired. These costs correspond to a range of anywhere from 1% to 3% of the capital cost, annually. This has generally covered one or two visits per year to visually inspect the system and change out consumables such as air filters for the cooling systems.

In order to reduce downtime from failed components, preventive maintenance efforts have become an important aspect of maintenance contracts. These programs rely on both remote monitoring data and visual inspections, typically annual, but can occur with more frequency if warranted. Key areas of inspection and testing include the battery system (power and energy capacity, RTE, sensors and cabling), balance of system (enclosure, fire suppression, HVAC) power conversion system (inverter, switchgear) and energy management system / communication.

Round-Trip Efficiency Losses

Round-Trip Efficiency (RTE) losses represent a key variable operating cost for energy storage facilities and can lead to significant negative economic impact—especially for more active usage profiles. As one would imagine, different energy storage technologies have different round-trip efficiencies based on the method needed to convert the electrical energy into a form for storage and back again. These charging costs will also vary between technologies as the round-trip efficiencies vary widely—flow batteries can achieve into the 80% range for round-trip-efficiency (DC-DC), whereas lithium-ion modules routinely state 95%+ round-trip efficiency (DC-DC).

In reality, average AC-level RTE values based on real-world experience are lower than the optimal values provided by manufacturers; for instance, lithium-ion systems are typically found to have an 80% to 85% RTE. Beyond the losses from

Either through competitive pricing or explicit mandates, utilities can choose energy storage assets to provide some of the expected peaking capacity for the areas.

Choosing energy storage assets for peaking capacity can provide a number of benefits for utilities. These assets can be deployed in smaller increments and are more flexible in their deployment—they do not need accompanying natural gas supply. They also can provide additional generation demand for existing baseload units at night, helping to increase their overall efficiency.

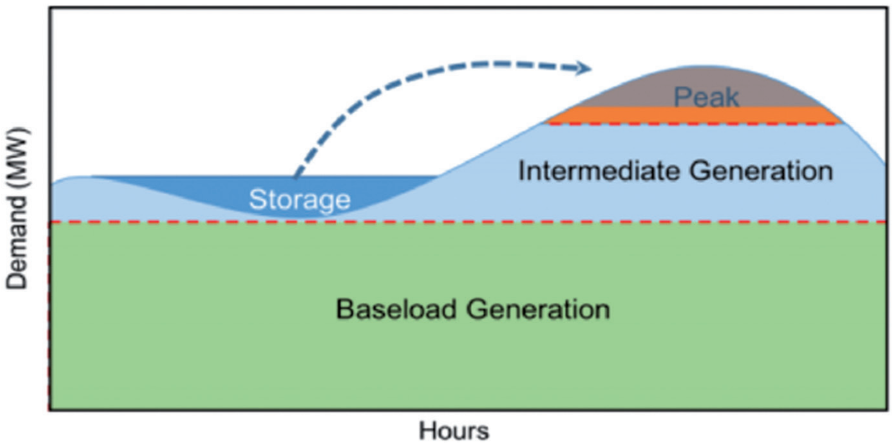

Figure 4.3. Peak Capacity Deferral[11]

Frequency Regulation

Frequency regulation (a.k.a. regulation) acts to stabilize the power grid by managing the moment-to-moment changes in the demand or supply balance of the power grid. The frequency of the AC power in North America is 60 Hz and is primarily maintained by system inertia from the rotating mass of power generators. As load changes, excess generation causes a frequency increase above 60 Hz; insufficient generation causes a decline below 60 Hz. Small shifts in frequency (load) do not degrade reliability, but large ones can damage customers' electrical equipment, degrade system efficiency, or even lead to a system collapse.

Changes in the system's frequency are first counteracted by the rotational inertia inherent in the connected synchronous generators. As the variation continues, regulation can also be provided through generating units operating under automatic generator control or participating in manual frequency control, both of which can change output quickly (on the order of MW/min). This service is contracted by ISOs/RTOs in the ancillary services markets. Although the concept is the same across the different organizations, the markets vary as to the technical