Future-Proofing Energy Storage
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Executive Summary

Energy storage capacity around the world is about to experience a sharp increase. According to the latest Energy Storage Monitor from GTM Research and the Energy Storage Association, the energy storage market will grow nine-fold between 2017 and 2022, with the behind-the-meter market, both residential and non-residential, accounting for up to half of the market by 2021. In dollar terms, the report estimates the energy storage market will be worth $3.1 billion by 2022. The authors expect energy storage deployments to cross the 1 GW per year mark in 2019, bolstered by improved economics and procurement programs.

At the same time, the investment case for storage is still difficult due to risks of limited technology track record and business cases that rely on uncertain revenues. With rapidly changing grid dynamics and the long-life requirement for storage assets, energy storage owners must future-proof their investments today.

In order to accomplish future-proofing of energy storage, storage developers must employ technology and project engineering specifically designed for flexibility. Future-proofing also requires commercial agreements and analytical expertise to optimize the operational value of energy storage.

In this white paper, Greensmith outlines not only the risks for energy storage systems owners, but also the strategies required to future-proof energy storage.
Introduction

In 2018, Energy storage analysts confirm that the industry shows no signs of slowing down as states begin compelling utilities to include it in their long-term planning processes. A total of 41.8 MW of energy storage projects were deployed in the third quarter of 2017, marking a 46% year-over-year increase from third quarter 2016, according to the latest Energy Storage Monitor from GTM Research and the Energy Storage Association. There were also 10% more energy storage deployments in the third quarter than in the second quarter, which saw a total of 38.2 MW deployed, the report said. The experts tell us that energy storage will reap the benefits of a strong foundation laid in 2017 — when regulated utilities took the helm of massive storage projects, after energy storage became a mainstream grid planning tool in 2016.

To provide some background on the topic, it’s important to note that in late 2015, the Aliso Canyon natural-gas storage facility in Southern California experienced a significant leak that put the grid at risk of power outages. In 2016, storage industry leaders installed three large lithium-ion (Li-ion) battery systems totaling 70 MW / 280 MWh to mitigate the power capacity shortage caused by the Aliso Canyon leak. After the projects were completed, California Public Utilities Commissioner Michael Picker said, “I was stunned at the ability of batteries and the battery industry’s ability to meet our needs. This was something I didn’t expect to see until 2020. Here it is in 2017, and it’s already in the ground.”1 Kevin Payne, the CEO of Southern California Edison, one of California’s large investor-owned utilities affected by the Aliso Canyon crisis, added that the commercial delivery of Li-ion battery storage in response to the crisis “validates that energy storage can be part of the energy mix now.”2

In addition to playing a high-profile role in the Aliso Canyon crises, energy storage systems (ESS) reached critical scale in grid deployments. For this paper, we define ESS to include all forms of stationary battery storage, including Li-ion and other electrochemical and flow batteries. We exclude large-scale infrastructure storage, such as pumped hydro and compressed air. This convention is followed by all the figures cited in this paper unless explicitly defined otherwise. Platts reported that as of Q2 2017, the installed base of ESS in the United States was 565.5 MW, and approximately one third of the capacity was deployed in the past year.3

While the total ESS market is growing, the MWh installed total is growing faster than MW installed, which indicates an increase in the average battery storage system duration. The installed cost of advanced energy storage has declined significantly in recent years, generally faster than market expectations. Battery storage technologies—primarily lithium-ion batteries—are declining rapidly in cost, dropping by 50% every three to four years and projected to continue at this rate. (IHS, Future of Grid Connected Energy Storage, Nov. 2015)

Considering this rapid and recent technical progress, it is critical for planners to use up-to-date advanced storage cost estimates and forecasts for IRP model inputs. We expect the trends of increased installations and longer system durations to continue. Both trends support a rapidly

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2 Ibid.
growing installed base of ESS. In terms of MWh of ESS installed, the market is forecasted to roughly double in size year over year until 2019 and then continue growing at an annual rate of about 35 to 40 percent.\(^4\) The U.S. ESS market size was $320 million in 2016 and forecasted to rise to $3.3 billion by 2022.\(^5\) Globally, the ESS market size was $1.5 billion in 2016 and forecasted to rise to $7 billion by 2025.\(^6\)

**Energy Storage Market Will Surpass $100 Billion by 2025**

While the ESS market is growing rapidly, a significant barrier to growth is financing risk. ESS assets are built to last 10 years or longer, and storage investors need ESS assets to deliver over the expected lifetime to realize pro forma project returns. However, long-term performance data for grid-scale ESS does not exist. In addition, many markets for ESS face uncertainties that make revenue forecasting a difficult task.

**Risks to ESS Owners**

**Risk 1: The Track Record of Grid-Scale ESS Projects Is Short**

The U.S. Department of Energy (DOE)’s Energy Storage Database shows that the median operating lifetime of grid-scale battery energy storage systems is 4 years and 9 months.\(^8\) Globally, there are only 14 grid-scale ESS projects that have at least 10 full years of operating history. In addition, many of these systems have been run as pilot programs, designed to test multiple applications rather than operating full-time as mission-critical resources like the systems being

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\(^7\) Lux Research, Quantifying Growth Opportunities in the $105 Billion Energy Storage Market, June 2017.
\(^8\) Includes electrochemical batteries with installed capacity greater than 1 MW
deployed today. Finally, major equipment vendors release new energy storage products every 12-18 months, meaning that past performance may not be indicative of future results.

Among ESS projects that have been operational for multiple years, the track record is mixed. Developers and utilities have piloted multiple battery technologies and are discovering the strengths and limitations of various storage technologies. For example, to accelerate the progression of grid-scale storage, the DOE invested in an early project in the ERCOT market to demonstrate the capability of advanced lead acid battery technology to provide renewable firming and frequency regulation. The DOE’s interest was to obtain technical and economic data from the project to prepare for future deployments. Once installed, operators found that the most lucrative application for ESS was Fast-Responding Regulation Service (FRRS), a pilot program in ERCOT designed to take advantage of the capability of fast-responding resources, such as ESS, to mitigate grid frequency deviations. Unfortunately, advanced lead acid batteries turned out to be a poor fit for the use case and experienced extreme degradation, which necessitated replacement years before the expected end of system lifetime.

Another storage system using advanced lead acid batteries in Hawaii caught fire. A third system, also in Hawaii, exhibited significant degradation after two years. Media reports in recent years have also documented failures affecting flow batteries, sodium-sulfur batteries, and flywheels. Li-ion battery systems, which make up the vast majority of battery systems today, have more positive preliminary performance results. However, with a limited install base, investors do not have the long-term field data to prove that such systems will perform positively in all project conditions.

**Risk 2: Market Revenues of ESS Are Uncertain**

ESS assets have a usable lifetime of 10 or more years depending on the ESS technology and usage profile. However, many of the key electricity market services that ESS provide are procured with short-term contracts. Other key market services are procured on a completely merchant basis via day-ahead bidding. Whereas wind and solar assets traditionally generate revenue for investors via long-term power purchase agreements, ESS projects often generate revenue via ancillary services and capacity markets, which do not always offer long-term contracts. The market value and procurement mechanism for these market services will change in unknown ways over the life of the ESS asset.

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The PJM Reg D market is a cautionary tale. PJM is a Regional Transmission Organization serving 165 GW of customer load across 13 states in the Northeast US. In 2012, PJM instituted performance-based regulation, an ancillary service, through a new automatic generation control signal called Reg D. The Reg D signal recognized the benefits that fast-responding ESS could bring to PJM ratepayers. The Reg D signal had no ramp rate limitations but was percentage, recognizing both the advantages and limitations of ESS when paired with traditional regulation resources. The faster response time of ESS allows a grid operator to reduce the total MW of ancillary services procured, providing cost savings for customers. With Reg D, PJM was able to reduce its regulation procurement target by 30%, from Figure 2 - PJM's 2017 signal change increased ESS energy throughput by over 50% and changed the energy neutrality condition from 15 minutes to 30 minutes.

1% of peak load to 0.7% of peak load. From 2012 to 2016, over 250 MW of ESS capacity was installed in PJM, equivalent to a capital investment of approximately $200 million.

As more ESS capacity entered the market, PJM encountered some operational and market design challenges. A contentious stakeholder process to reform the market stalled, and PJM unilaterally changed the Reg D signal characteristics in January 2017. The new signal targeted energy neutrality over a 30-minute period and required an incremental energy throughput of greater than 50% that of the previous Reg D signal.

These changes adversely impacted all ESS projects in PJM. An ESS project designed to provide a fixed amount of power for 15 minutes cannot maintain its power capacity or increase energy throughput without affecting battery performance, warranty terms, and even safety considerations. A 10 MW system built for a 15-minute duration has 2.5 MWh of usable energy capacity. If a 30-minute duration is required, then the system's power capacity must be limited to 5 MW so it can continue to yield 5 Figure 3 MW as ESS duration requirement incr– Indicative illustration that ESS capacity drops from 10 MW to eases from 15 minutes to 30 minutes

14 “Performance-Based Regulation: Year One Analysis”, Regulation Performance Senior Task Force PJM Interconnection, October 12, 2013.
the same 2.5 MWh of energy capacity. Most PJM battery system operators responded to the Reg D signal changes by simply cutting power in half and reducing system availability, but since revenue is based on capacity and availability, these operational changes reduced investor revenue by greater than 50%.

Greensmith, by contrast, made software and physical site changes to maintain a high system availability and keep the rated capacity of our systems greater than 50%. We did this by reevaluating all the tradeoff decisions that go into ESS operation. For example, because the Reg D signal change increased energy throughput, we reduced ESS temperature, which decreased degradation but also decreased round-trip efficiency. Because the signal change modified the energy neutrality condition, we modified our state-of-charge management algorithm, which impacted energy throughput and system performance. These changes were enabled by futureproofing with a flexible controls architecture, which we will discuss next. While future-proofing saved Greensmith customers millions of dollars in PJM, other PJM systems faced tremendous losses. Investors looking at the experience of the PJM merchant market for Reg D will use caution when entering into future merchant markets for ESS.

Faced with a limited track record of the ESS installation base as well as market uncertainty, how can an ESS investor mitigate risk? The only option is to future-proof current ESS investments to plan for changes in the future. ESS projects can be future-proofed by: 1) installing a flexible controls architecture, 2) planning the right way for battery capacity augmentation, and 3) tracking ongoing operation with a flexible warranty.

Strategies to Future-Proof ESS

Strategy 1: Design for Flexibility

One solution for dealing with technology and market uncertainty is to design for ESS flexibility with an augmentation plan over the ESS project lifetime. In an augmentation plan, additional battery capacity is added to

Case Study: National Grid (UK)

Market Overview

The United Kingdom is poised to become one of the largest ESS markets in the world. National Grid, the UK grid operator, has announced its intention to procure ESS for grid balancing services through its Enhanced Frequency Response (EFR) and dynamic Firm Frequency Response (dFFR) market products.

The UK has a need for incremental resources for balancing services due to multiple market drivers, including increased wind penetration, retirement of large synchronous coal-fired generation, and limited interconnection capacity with neighboring grids.

Market Uncertainty

ESS owners that win EFR or dFFR contracts face uncertainty in evaluating what the market for balancing services in the UK will look like after the expiration of their contract terms (up to 15 years). In addition, many ESS projects that are providing EFR and dFFR are “value-stacking” by also bidding into the UK capacity market. Prospective owners need to plan for flexibility in their current installations.

Future-Proofing Approach

For National Grid EFR and dFFR projects that are participating in the capacity market, Greensmith offers an ESS design with spacing and cabling pre-planned to modify battery storage duration at a future date. The flexibility of the GEMS platform also enables a mix of high-power battery cells from the initial design with high-energy cells in the future design to minimize cost and plant footprint at initial deployment and after augmentation.

Lastly, the Greensmith EFR/dFFR system design benefits from a flexible warranty that adjusts according to system throughput.

Until now, many investors have perceived the risks in the UK ESS market to be too high. The ESS investment case depends heavily on revenue generation coming after National Grid’s current contracted revenue period. With the combination of intelligent software, careful planning, and warranties that address customer needs, system owners can future-proof their investments in the burgeoning UK battery storage market.
the project site. The augmented battery capacity can be used to supplement planned battery capacity losses due to battery degradation, or to provide incremental capacity if future market conditions support a larger system.

While augmentation plans make sense in concept, few installed energy storage systems today have been planned for augmentation. As such, there is no long-term track record of augmented battery storage systems. In addition, there are different schools of thought about how to safely and effective augment ESS projects.

In designing for flexibility, it is crucial to plan the ESS layout for inverter-based augmentation. This design requires leaving sufficient space for additional battery racks, and designing wiring and cable trays for the future state of the system where some racks have moved and additional racks are added.

The appeal of battery rack-based augmentation is that, in theory, it could be less costly. Battery rack-based augmentation would allow an ESS owner to add the minimum incremental storage capacity necessary, conduct multiple augmentations, and eliminate the labor from moving previously installed racks at the time of augmentation. However, battery rack-based augmentation renders a system unsafe to operate. As batteries age and degrade, their internal resistance increases. When new batteries are installed in parallel with old batteries, the new batteries will operate at higher currents than the old batteries. These higher currents will exceed the current limitation of the conductors, over current protection devices, switches, and contactors in the power path. Therefore, battery rack-based augmentation is not a feasible approach to future-proofing energy storage.

Figure 5 – Hypothetical augmentation scenarios. The charts assume a central inverter design, which is representative of most operating energy storage systems.

With an inverter-based augmentation, batteries will be wired in parallel only with other batteries of the same vintage. The older batteries will have a similar state of health, and therefore they will have similar resistance and current output profiles. The new batteries may have different characteristics, benefitting from higher performance, lower cost, and a smaller footprint, and thus requiring a smaller initial capacity than batteries from the original deployment. A second augmentation may be possible, but it depends on system size and the number of original batteries and central inverters.

When designing for flexibility, do not assume that battery rack-based augmentation will be possible.
An alternative is rack-based inverter design. In this scenario, racks are wired in parallel on the AC side of the inverter rather than the DC side. A rack-based inverter configuration allows for more design flexibility for future augmentation but can be less cost effective. The selection of the right approach is dependent on the degree of flexibility desired by the system owner.

Strategy 2: Employ a Flexible Architecture

There are two primary controls architectures for an ESS Energy Management System (EMS): PLC-based and PC-based.

A programmable logic controller (PLC) is a hardened industrial computer, designed originally for assembly lines. PLCs are “hard” systems in that they are programmed for a specific task, and they accept limited inputs and outputs to accomplish the task. In the context of an energy storage EMS, PLCs are typically designed by inverter manufacturers and coded for a specific inverter and battery technology. Modifications are possible, but they take significant time and effort and typically require an engineer on-site for months at a time. This makes the cost of PLC modification relatively high.

A personal computer (PC)-based controller is built on multipurpose industrial servers and is controlled by software. The PC-based architecture facilitates complex operation and optimization and allows for updates to be delivered faster and at lower cost. The Greensmith Energy Management System (GEMS) controls platform is designed with a technology-neutral architecture, meaning that the same controls platform can be used with any battery and inverter technology with minimal configuration. Greensmith tests all software modifications on a virtual machine that replicates the technology characteristics of each piece of hardware. Updates are performed only after the software has been fully debugged in a lab environment. Updates are installed remotely via a secure VPN and require only 5 minutes of downtime.

Case Study: CAISO (California)

Market Overview
The California Public Utilities Commission requires distribution utilities to procure capacity commitments of at least 115% of their peak loads. This requirement is met through bilateral Resource Adequacy (RA) contracts between utilities and generation owners. For limited energy resources such as ESS, RA contracts are defined to require four hours of discharge duration at rated capacity. Most grid-scale ESS projects in California are four-hour systems because RA is the most lucrative revenue stream for ESS. The RA rules also require generators to bid into the CAISO market during most hours of the day so that CAISO knows these assets are online and available.

Market Uncertainty
While many California ESS assets have signed RA contracts for 10 years with utility off-takers, CAISO frequency regulation is an entirely merchant market revenue stream. Frequency regulation could be highly lucrative or near worthless in the future. RA contracts have fixed capacity requirements, so an energy storage owner must plan to meet the fixed capacity requirement over the life of the 10-year contract either by oversizing the system for 10 years of planned degradation or by planning for an augmentation of energy storage capacity.

Future-Proofing Approach
For California RA systems, Greensmith offers an augmentation plan, which it has put into place in a 20 MW/80 MWh project deployed in California in 2016. Under this plan, GEMS will track the warranted capacity of the batteries and display trend values over time. At the same time, Greensmith designed for flexibility with a planned inverter-based augmentation at a pace that fits with the owner’s schedule. By tracking the battery’s flexible warranty, GEMS enables the system owner to make tradeoff decisions for various market conditions. This flexible approach provides the investor with more confidence that merchant revenue is attainable, which boosts returns and allows for competitive bidding in RA tenders.
The PC-based flexible architecture enables various degrees of flexibility that each contribute to ESS future-proofing. In PJM, the flexible architecture allowed Greensmith to react quickly to adverse changes in the market. In other cases, the flexible architecture has allowed Greensmith to easily repurpose ESS assets when market changes allowed for incremental value. A table of case studies demonstrating the capability of a PC-based architecture is shown below. Many of these deployments are technically feasible on a PLC, but would have been much more complex and costly, negating the commercial case for deployment.

<table>
<thead>
<tr>
<th>Capabilities enabled with a flexible PC-based architecture</th>
<th>Date</th>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repurposing of existing ESS asset</td>
<td>2011</td>
<td>California</td>
<td>50 kW ESS sold from initial owner to secondary owner and repurposed for new use case with remote software update</td>
</tr>
<tr>
<td>Dual battery operation</td>
<td>2015</td>
<td>Virginia</td>
<td>60 kW ESS (50 kW flow + 10 kW electrochemical), unified control platform</td>
</tr>
<tr>
<td>Co-optimization of multiple generation assets</td>
<td>2015</td>
<td>Puerto Rico</td>
<td>1 MW ESS + 2 MW solar, unified control platform</td>
</tr>
<tr>
<td>Flexible augmentation plans (one controller optimizing the output of batteries with different vintages and performance characteristics)</td>
<td>2016</td>
<td>California</td>
<td>20 MW, augmentation pre-planned for 2021</td>
</tr>
</tbody>
</table>

**Strategy 3: Track Ongoing Operations for Flexibility with Warranty**

Li-ion battery warranties are complex. Warranty terms differ by battery vendor and model. Typical terms include:

- Annual energy throughput
- Peak DC charge/discharge rate
- Daily average DC charge/discharge rate
- Average daily temperature
- Maximum temperature deviation across measurement points
- Common mode noise level (voltage)
- Common mode noise level (current)

If one or more of these conditions are violated, or if the system is operated in a different manner than modeled, the system owner faces a reduction in warranted usable energy. Many of the battery warranty conditions have a direct correlation to battery usage and system revenue, which leads to tradeoff decisions regarding how the system is used. Is it better for a battery storage owner to operate the system aggressively and chase additional revenue, or operate it conservatively to maintain a higher warranted usable energy over time? The only way for system owners to make informed decisions is to track all values using dashboards and analytics. These are core functions of the GEMS platform.

- The battery management system (BMS) does not track all warranty conditions. So, if a warranty claim arises, relying solely on the BMS is not sufficient to ensure warranty compliance. Without an energy management system to track all energy storage performance data, the system owner is not protected in event of failure. In addition, tradeoff decisions regarding changes in battery operation within the terms of the battery warranty are not possible.

**Conclusion**

In the United Kingdom and California, two early and significant markets for energy storage, success for storage owners is only possible if investments are future-proofed. In both markets, investors must plan to future-proof energy storage to take advantage of revenue streams that are not contracted. These revenue streams are uncertain, so a flexible system design is necessary to be confident that the revenue streams are attainable. In the UK, the revenue risk includes frequency response revenue in the years after an EFR or dFFR contract has expired, as well as future changes in the capacity market. In California, the risk includes frequency regulation revenue, which augments revenue from a bilateral capacity contract. In both markets, storage owners that do not assume additional merchant revenue in their project pro-forma will be unable to compete in solicitations for long-term contracted revenue. Once projects are built, the measures taken to future-proof ESS will make the difference between realizing revenue expectations and being left with stranded assets. It is prudent to choose solutions that have been built with flexibility in mind. Regardless of the changes that come to battery storage technology or energy storage market revenue, flexible systems will allow you to achieve optimal storage results.