Energy storage and energy density: an EPC's view

System integration | Energy density is becoming a key tool in optimising the economics of battery energy storage projects as suitable sites become harder to find. Ben Echeverria and Josh Tucker from engineering, procurement and construction firm Burns & McDonnell explore some of the considerations of designing projects on constrained land

Credit: Burns & McDonnell

Taller battery racks are one option for increasing energy density as battery sites become more constrained

When transmission authorities in the USA first began to realise that utility-scale storage facilities would be necessary to help manage the intermittency of renewables being connected to the grid, land availability was not a concern. With Arizona, California and Texas leading the way, land was readily available for large project footprints.

Given both space and favourable market conditions, buildout was not an issue and, as a result, those three states currently contain more than 75% of today's battery storage capacity nationwide.

Those early market conditions are no longer the reality. Sites with large amounts of available land near transmission interconnections are becoming increasingly less available, and that can make today's project sites more challenging, especially as demand for these facilities continues to grow. A range of federal tax incentives and state mandates is creating more momentum for decarbonisation efforts than ever, further increasing the demand for large-scale battery energy storage systems (BESS).

Sites may still be available near interconnection locations, but they typically have much smaller footprints, and as a result of constrained supply and high demand, land prices in these situations are increasing. As a consequence, developers are seeking to significantly increase the amount of energy storage per acre. This drive to optimise project economics is being pursued by seeking more energy-dense batteries while also optimising the available site footprint.

What is energy density?

The volume of energy contained in each battery cell can play a pivotal role in project economics. The standard definition of volumetric energy density is the amount of energy a battery can store in proportion to its volume (specific energy density is stored energy in proportion to its weight). To be clear, we will be referring to energy density in this article as volumetric energy density. The industry has progressively improved upon battery energy density, with lithium-ion batteries increasing the energy available in the same footprint by about 10-12% over the last year.

Of the most common lithium-ion battery chemistries used today, nickel manganese cobalt oxide (NMC) and nickel cobalt aluminium oxide (NCA) battery technologies are the energy density leaders. Lithium iron phosphate (LFP) battery technology is another common battery chemistry, but it is much less energy dense. More recently, however, LFP has made gains in this area with some believing there is significant opportunity for this chemistry to attain densities close to NMC and NCA.

These lithium-ion technology advances, including energy density, are being largely driven by demands from the electric vehicle (EV) industry for improved ranges and performance characteristics for batteries installed in vehicles. Because the power industry holds such a relatively small share of the lithium-ion battery market, the reality is that advances in utility-scale BESS installations will likely move in lockstep with the auto industry. Supply chains, manufacturing advances and general use cases for battery technology all are heavily weighted toward meeting auto industry demands.

On the horizon, it seems that very large, energy-dense battery cells will be developed to produce more energy from increasingly smaller volumes. With new and improved electrolytes, anode advancements and cathode evolution, ranges for EVs and output for storage facilities can be greatly improved.

Building up, not out

In densely populated metropolitan areas like Los Angeles, New York City and Boston, decarbonisation efforts are creating unique challenges for battery energy storage projects.

New York is an interesting case example. Though actual numbers will vary by the time of season, it is generally assumed that approximately 70% of the power load within the state of New York is centred around demand from New York City. As New York utilities move toward meeting regulatory mandates for reduced or zero-carbon emissions, thermal generation systems are being ramped down or retired. Renewable energy backed by storage-based power systems will be needed to fill the gap.

It is logical to locate these renewables and storage systems within the city. In New York City, smaller facilities in the 5-20MW range are being planned and developed. As deadlines for decarbonisation grow closer, it seems likely that these smaller projects will fall short of demand and larger projects will be needed.

However, the reality is that within large, dense urban areas, only small plots of land are available. The only realistic and economically viable option is to design these projects vertically, either with batteries installed in enclosed building structures or with vertically stacked battery enclosures. If the building is the preferred solution, this may involve stacking multiple racks to increase total rack heights up to 15 feet, versus the conventional seven-foot racks. This could involve the building having multiple stories of these taller racks.

With this configuration combined with higher energy density within battery modules themselves, the overall energy capacity will come close to meeting higher energy demands of these metro areas.

Going vertical is more complex

Though numerous projects are now on the drawing board, it must be noted that no high-rise BESS facilities are currently operational.

That's because going vertical requires careful evaluation of operations and maintenance impacts, including installation of robust safety systems. These analyses shift the focus from performance and design of modules toward a holistic look at the entire site. Considerations will be given, for example, to the broad operational effects of utilising heavy mechanical equipment in compact spaces that must operate safely.

Operating conditions for vertical BESS projects — as well as conventional projects — must be evaluated for each site. Storm and flood risks, relative humidity, seismic considerations and prevalence of salt within coastal air are among the environmental factors that can affect how the site will be designed and operated. The development of an operations and maintenance programme should include evaluating tolerances of all critical battery chemical processes in parallel with design, safety and equipment decisions.

There is a range of battery storage enclosure design options available, but all must account for the challenges of airflow, thermal management and accessibility for routine maintenance.

Enclosing a BESS facility in a multi-level steel structure may have advantages in accommodating equipment and incorporating critical safety systems. Alternatively, an open-air design, similar to a mezzanine, can create an accessible internal layout with systems on different levels. Many innovative variations of enclosed and open-air systems go beyond rack storage or purpose-built solutions. Most can accommodate modular design options and must be evaluated to select the right approach to meet unique project challenges and goals.

Other options for density

Battery suppliers are modifying cell and module designs and footprints, along with enclosure designs, to maximise battery density and to decrease spacing between enclosures. Numerous creative designs are currently being developed to make maximum use of space, thus increasing energy density for the project site.

One realistic constraint is the tonnage that can be feasibly transported to the job site and then lifted into place either by crane or forklift. This becomes a logistics challenge that starts as a total turnkey operation from the original manufacturer (primarily in Asia), transport to a container ship, offloading to a truck, transporting to the project site and final offloading to be set in place.

Planning for these highly energy-dense facilities also must factor in degradation of battery performance over time. The operations and maintenance strategy should incorporate a workable installation process to augment battery capacity over time as the overall system degrades, and/or to overbuild the system from the start to extend the time frame when augmentation is to occur and thus reduce the amount of battery augmentation required. Augmentation is explored in more detail on p.95.

What about safety?

Thermal runaways start as a short circuit within or external to the battery cell that triggers an exothermic reaction. The electrolyte is quickly vaporised in an off-gassing process that then proceeds to chemical reactions between the metals and minerals within the battery. These reactions produce enormous heat and explosive gases that can lead to fires and/or explosions if the event occurs within a contained space that is not ventilated.

The amount of heat and gas emitted during a thermal runaway event is dependent on several factors including the battery's state of charge — in other words, the amount of energy within a battery cell compared to its full capacity. That means that as battery cells are designed to store more energy, thermal runaways can become more intense. Thermal runaway events within NMC and NCA batteries generate more heat, which in turn causes a greater chance of thermal runaway propagating to other cells and modules. NMC and NCA battery chemistries also tend to have a flame associated with a thermal runaway event that can burn off the explosive gases that are emitted from the battery.

LFP technology does not emit as much heat during a thermal runaway event due to the chemistry and metals utilised, and thermal runaway events for LFP can have a lower risk of thermal runaway propagation. However, this chemistry can pose another set of risks.

Due to heat values being lower and lack of flame during a thermal runaway event, LFP chemistry can create more explosive gases that can raise the risk of explosions for these batteries located in contained spaces.

Fire suppression systems for all lithium-based technologies currently aim primarily to protect the building and related enclosures. There is no silver bullet for stopping thermal runaway within the lithium-ion technology group, simply because it is a chemical reaction that is hard to stop once it begins.

Effective thermal management programmes may utilise HVAC (Heating, Ventilation, and Air Conditioning) or chiller systems that aid in maintaining operational stability while lowering the risk profile for batteries to go into thermal runaway

Credit: Burns & McDonnell

due to thermal abuse. For example, direct expansion air handling units using refrigerant liquid are an option. Though these are reasonably cost effective to install, it must be noted that efficiency decreases over time. Central utility plant designs incorporating large centrifugal chillers are another option that can be used to distribute cooled water across large interior spaces. This proven technology offers the potential for redundancy and greater operational flexibility. Placement of racks in vertical configurations can add another element of thermal management by creating different heat zones and hot and cool aisles.

Other battery chemistry options

Though there are a number of non-lithium technologies in development, none to date can compare to the energy densities, better efficiencies and lower capital cost of lithium-ion batteries.

Several non-lithium battery technologies are proven but are unlikely to unseat the dominance of lithium-ion anytime soon because of its overall scale and the maturity of supply chains for commodities and materials needed for mass manufacturing. Unless a technology emerges with the scale and economic viability to support a robust supply chain, we are unlikely to see another dominant technology emerge in the utility-scale energy storage market in the near term.

If it weren't for the demand for batteries generated by the automotive industry, it's difficult to predict what type of storage technology would be emerging to meet the changing demands of the power industry. The known alternatives currently provide only a fraction of the energy density currently available from the primary lithium-ion battery technologies. The round-trip efficiencies — defined as the percentage of electricity put into storage that is later retrieved (i.e., the higher the round-trip efficiency, the less energy is lost in the storage process) — are not as high with alternative battery and other storage technologies at present.

Flow battery technologies, for example, offer certain advantages such as longer output duration and longer cycle life, but are hampered by lower round-trip efficiencies.

The market dynamics will change as more thermal power plants are retired. As dispatchable power units with capacity to provide many gigawatts of round-the-clock baseload power leave the market, use cases for long-duration storage will increasingly come to the forefront. Though market dynamics currently favour lithium-ion BESS facilities, that could change if these facilities were needed to provide round-the-clock power output. In order to offset the loss of a 600MW coal plant that had provided baseload grid power, it would require 14,400MWh over a single day.

No project is identical

It is difficult to forecast precisely how the battery energy storage market will evolve because it is changing so quickly. With battery technologies changing rapidly, project execution from year to year can look very different.

Energy density has become a priority for both operational and financial reasons, but to date most of the advances have come primarily from the batteries and secondarily from space optimisation within enclosures, along with creative enclosure configurations.

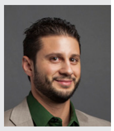
Energy density has become a priority for battery OEMs to help reduce total project cost and fit more capacity within small footprints. However, as the grid continues to change and the market shifts to deeper decarbonisation, it is unclear whether energy storage technologies will advance enough to meet the demand for baseload power. Ultimately, money is the driver within any market, and with the reduction of capital it may be that planners and policy makers begin to conclude that it is imperative to adjust policy or regulatory drivers to keep pace with continued increases in capital cost, or to provide further incentives to advance the development of lithium-ion technologies and other technologies.

The tonnage that can be feasibly transported to land-constrained sites is one consideration to make

One possible sign to indicate the technology advancement for the energy storage market is shifting is the development of battery cell types geared specifically to meet the needs of the power industry. The energy storage market previously used battery cells generally designed for the EV market and not necessarily designed with a use case for the storage market. By optimising the cell design for storage applications, it is likely that improvements in degradation and cycle life (i.e., life of the battery) can be achieved. In fact, some manufacturers are starting to offer a 25-year performance guarantee (based on one cycle per day) for certain battery types.

As more fossil-based thermal generation will be exiting the market, that capacity must be replaced by other sources along with energy storage playing a key role. As these energy storage systems are moving into more urban areas, energy density and land availability will be topics of great interest for the foreseeable future. ■

Authors



Josh Tucker is engineering manager for the Energy Storage Department at Burns & McDonnell. He has over 17 years of professional experience in electrical engineering, construction execution, and engineering and project management. He is responsible for all engineering for the energy storage business. His experience includes engineering and project management on EPC projects, engineering on power distribution systems, control interfaces, and protection for auxiliary electrical systems for coal fired power plants, simple and combined cycle power plants, and energy storage systems.

Ben Echeverria, energy storage regulations and compliance at Burns & McDonnell, is responsible for assisting the EPC project teams on energy storage projects globally, focusing on the safety, regulations and overall compliance of the interconnected systems. He helps to coordinate all the project stakeholders including project end-users or owners, insurance carriers, and direct communications with the project's Authorities Having Jurisdiction. He is a voting member on UL9540(A), UL1973, UL1741, and currently working on task groups within NFPA 855.