FRIDAY, JULY 15, 2022

A FOCUS ON BATTERY ENERGY STORAGE SAFETY

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As lithium-ion batteries scale, mitigating the risk of fires becomes more important

By Chris Warren

Projections about the future growth of energy storage are eye-opening. For context, consider that the U.S. Energy Information Administration (EIA) reported (https://www.eia.gov/analysis/studies/electricity/batterystorage/) that 402 megawatts of small-scale battery storage and just over one gigawatt of large-scale battery storage were in operation in the United States at the end of 2019.

By 2023, however, the EIA forecasts an additional 10 gigawatts of large-scale batteries will be installed in the United States. Globally, investments are pouring into energy storage projects, with projections (https://www.fortunebusinessinsights.com/industry-reports/battery-energy-storage-market-100489) putting the total market size for batteries at nearly $27 billion by 2028.

The fundamental reason for this big upswing in investments and deployments of energy storage is clear. As the global electricity mix adds large amounts of generation from variable sources like wind and solar, battery energy storage is crucial to reliably deliver electrons when the sun isn't shining, and the wind isn't blowing.

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As battery energy storage grows in scale and importance, the need to ensure that these systems are designed, installed and operated in as safe and environmentally responsible a manner as possible also increases. As battery storage systems today overwhelmingly utilize lithium-ion technology, the industry must take steps to prevent and mitigate potential fires and preparing effective responses for the rare instances when they occur.

EPRI's battery energy storage system database has tracked over 50 utility-scale battery failures, most of which occurred in the last four years. One fire resulted in life-threatening injuries to first responders. These incidents represent a 1 to 2 percent failure rate across the 12.5 GWh of lithium-ion battery energy storage worldwide.

Collecting the Data Needed to Address Fire Risks

To better understand and bolster the safety of lithium-ion battery storage systems, EPRI and 16 member utilities launched the Battery Storage Fire Prevention and Mitigation initiative in 2019. The initiative is one of several EPRI-led efforts seeking to identify the root causes of battery failures and to improve and share knowledge about effective response strategies. These initiatives have included creating a battery storage fire safety roadmap, developing recommendations and leading practices for designing systems, and training and working with first responders responsible for putting out fires.

The work seeks to provide research-informed education to the owners and operators of lithium-ion batteries and to first responders. In that task, EPRI and its partners have an important advantage. "There are a lot of industries that deal with explosive things. We have very well understood methods of managing explosion hazards," said Dirk Long, a principal technical leader at EPRI, who is spearheading much of the research. "But nobody was looking at explosion hazards when most of these systems were built. People haven't been pointing their brains at the right problems and haven't had good data about how to solve them. This work is meant to address that."

The research is also meant to provide utilities with the information and tools they need to be comfortable with lithium-ion technology. "When utilities see these fires, they ask whether they should even use lithium batteries," Long said. "I think that's the wrong response. It's a matter of taking all the lessons learned, paying attention to the right problems, and solving them in our industry."

For example, the automotive industry has recognized the importance of system designs that prevent a single-cell thermal runaway from propagating. This lesson has become an industry-leading practice and was added to the latest UL standards for electric vehicle battery packs. "That is a type of systems thinking built on a decade of lessons learned in that industry," Long said. "We can pull that learning into the stationary energy storage market."

Understanding Thermal Runaway

EPRI's work is primarily focused on preventing failures and responding to them effectively if they occur. To do both of these well, it's vital to understand what can cause lithium-ion battery explosions and fires. "The fundamental cause of the hazards we worry about with lithium-ion batteries is thermal runaway," Long said.

At the most basic level, thermal runaway in a lithium-ion battery occurs when a failure of some type leads to overheating inside the battery cell. "It's the electrochemistry decomposing in its own kind of way that generates a lot of heat and creates a self-accelerating reaction," Long said. "It may cause fires, and it releases a lot of gases that are flammable and can cause explosions." Past EPRI research identified four root causes of thermal runaway: internal cell defects; faulty battery management systems, including bad hardware or software; insufficient electrical isolation; and environmental contamination from things like humidity and dust.

Much has already been learned about how to reduce the risk of thermal runaway. For example, EPRI conducted eight site visits to lithium-ion battery storage projects in the United States. The sites included systems being designed, under construction, and already operational; the systems varied in size from 0.3 MW/0.6 MWh to 182 MW/730 MWh. EPRI's safety review of these sites included analysis of data (design documents and equipment certifications), site walkthroughs, and assessment based on fire hazard mitigation guidance from the Energy Storage Integration Council.

Based on those assessments, EPRI developed lessons learned and guidance about steps that could be taken to improve safety. "We found that even though utilities had a lot of awareness around safety concerns, each one had a number of site design features that could be retrofitted to improve safety," Long said.

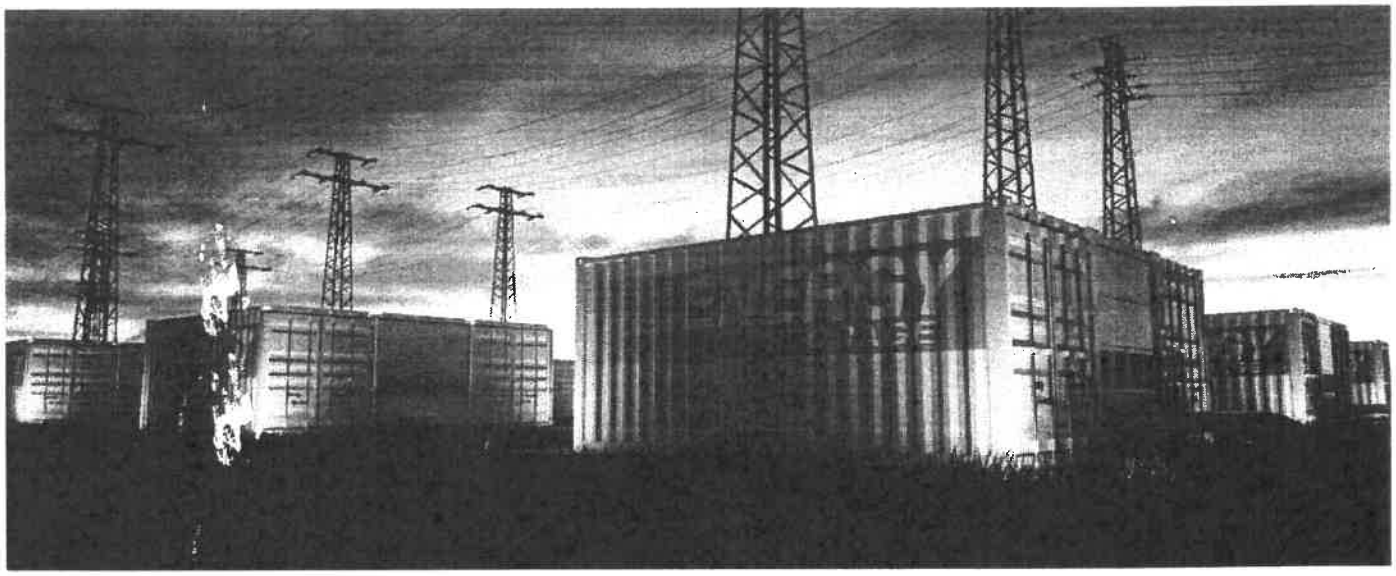
The findings of this research include the following.

Safety evaluations are influenced by subjectivity—There is a fundamental difference between evaluating a battery system to understand its performance and failure modes, and conducting a safety evaluation. Performance and safety vulnerabilities can be analyzed objectively using quantifiable data. By contrast, safety evaluations are inherently subjective, guided by factors such as the evaluator's experience and expertise, the system owner's tolerance for risk, and interpretation of safety-related data. The roles of those assessing safety also influence their perspective and priorities. For example, some fire protection professionals are experienced in hazardous material fires, while others have specific experience with safety events involving lithium-ion or other battery storage chemistries. To maximize safety, it is important to match the expertise and experience of those completing safety evaluations with the system design and technology at individual sites. Doing so also reduces the time required for an evaluation because the experts involved are already familiar with potential safety vulnerabilities and the possibility of missing risks.

Ownership models determine safety management and responsibilities—Clear lines of responsibility enhance the safety of battery energy storage systems. In assessing multiple storage system sites, however, EPRI observed that differing ownership models cloud safety management responsibilities. Adding to the confusion, large battery systems are often operated by a mixture of vendors and owners, which can blur responsibility for taking steps to mitigate safety risks. Clearly understanding and communicating safety roles and responsibilities are essential to improving safety.

Common safety data support a common evaluation process—The optimal approach to assess the safety risks of a battery energy storage system depends on its chemical makeup and container. It also relies on testing each level of integration, from the cell to the entire system. In addition, it's important to apply the appropriate safety testing approach and model to each battery system. For example, one of the EPRI assessments determined that an incorrect data set was used in safety testing; the data used represented a different battery module than the one to be installed at a site. When the proper data were used, new explosion risks were found, which necessitated a redesign of the battery enclosures.

Planning for failure requires decisions about acceptable levels of damage—It is impossible to completely eliminate the risk of a battery system fire. Steps to mitigate the chance of a fire or explosion inevitably involve choices and trade-offs. A recent EPRI study looked at the cost of safety design features in relation to a system's total cost of ownership. Some owners may accept the possible failure of a system and its components as well as the costs of cleanup necessary after an event rather than bearing the expense of additional safety measures. Others may decide that the possible loss of storage capacity and the expense of cleanup compel greater investments in mitigation and prevention.



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Responding to Fires and Other Safety-Related Events

Taking steps to prevent thermal runaway can reduce but never fully eliminate the potential of its occurrence. "There's always a non-zero risk that a battery will enter thermal runaway, even if it's a really low risk," said Stephanie Shaw, a technical executive at EPRI whose research focuses on assessing and reducing the environmental and health impacts of energy generation and storage. "You also have to always be looking at what comes after and managing all the outcomes from that kind of failure." Shaw's research has explored topics such as the composition of combustion air plumes, the water used to extinguish battery fires, and the potential risks to first responders and the public from those releases.

To help maximize the effectiveness of response to fires and other safety incidents, EPRI hosted a workshop with utility representatives, researchers, first responders, and fire safety experts. The aim was to gather insights and leading practices to inform how different stakeholders should communicate and prepare for possible safety incidents.

The resulting report, *Proactive First Responder Engagement for Battery Energy Storage System Owners and Operators* (https://www.epri.com/research/products/000000003002021774), outlines actions to improve safety while also speeding the deployment of projects and lowering their costs. The recommendations all focus on steps to be taken before battery storage systems are installed or before they begin operation.

The recommendations are wide-ranging and include guidance on an overall approach to the leading practices to follow. They apply to stages from procurement through installation, as well as to both learning from and training first responders about some of the unique challenges of battery fires.

A few of these recommendations are summarized below.
(https://eprijournal.com)

Open communication during the storage system design phase—Close collaboration and communication between first responders and battery energy storage owners and operators is always important. It should begin well before installation of the system begins. Often, it only starts during the permitting process, when designs and plans for construction may already be complete. This is a lost opportunity. When dialogue begins earlier, first responders can provide input about the most effective fire suppression and containment systems as well as direction on the ideal distance between battery systems to avoid propagation of a fire to other units and containers. First responders can also educate utilities about their typical response protocols. This information can then be integrated into incident response systems. Other guidance covers development of utility expertise on battery safety and completion of a comprehensive safety evaluation at each storage system facility. Another important leading practice is for utilities to identify a safety lead at each battery site. This gives first responders a knowledgeable contact to communicate with if an incident occurs.

Smart design and an emergency response plan—Firefighters need reliable access to water. Other design features to consider include the presence of multiple alarm systems in case one fails; limits on charging and discharging levels as well as well-defined temperature and voltage ranges; and clear signage showing the location of emergency disconnect switches. Additionally, an emergency response plan that details the procedures for shutting down the battery storage system avoids confusion and risky delays in response.

Collaboration with and help training first responders—Firefighters need to be aware of the design of a battery storage system and the layout and fire protection systems in the facility where it's installed. The owners and operators of battery energy storage systems should proactively ensure that first responders have that information and should actively solicit their feedback. Storage owners should also make battery storage experts available to first responders and provide ongoing training to help ensure they are prepared in case of an incident.

The main takeaway from the engagement with utilities, first responders, and the owners and operators of storage systems is to be proactively and continuously collaborative. For utilities and storage owners and operators, it's also important to listen. "It's important to help train first responders, but more importantly to be trained by them, because they have insights and practices from responding to fires that can apply here and protocols that must be followed," Shaw said.

EPRI is currently working on a range of resources to help improve the safety of battery energy storage systems called the *Project Lifecycle Safety Toolkit.* It will include everything from data sets to white papers and guidebooks that provide practical steps to mitigate the risk of a battery fire and to optimize the response in case it occurs.

"These are about helping the industry take the first step towards safety," Long said. "Most of the problems we know how to solve if you get people started on it. We think that once you get enough smart people pointing their brains at the right problem, they'll be able to solve it collectively."

EPRI Technical Experts:

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Focus on Battery Energy Storage Safety).

Additional Resources:

- Proactive First Responder Engagement for Battery Energy Storage System Owners and Operators (https://www.epri.com/research/products/000000003002021774)

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