WHITE PAPER / **LITHIUM-ION BATTERY SAFETY**

PROMISING OUTLOOK FOR LITHIUM-ION BATTERY TECHNOLOGY — ONCE RISKS ARE ADDRESSED

BY Chris Ruckman, PE

Lithium-ion batteries have become the technology of choice for utility-scale energy storage configurations. Further growth will depend on how manufacturers and the utility industry address battery safety challenges.

Lithium-ion batteries are here to stay. Use cases are growing every day. Cell pricing continues to decline and manufacturing is ramping up to meet global demand. At the same time, battery energy density continues to improve, and manufacturers are developing more cost-effective packaging to reduce installation costs. And, finally, though current fire safety concerns are serious, they can be addressed with proper equipment selection, planning and engineering.

Any discussion about the future of lithium-ion technology typically starts with cost. In 2010, lithium battery pack pricing was around $1,200 per kilowatt-hour (kWh) for large-scale storage configurations. As of early 2020, pack pricing was less than $160/kWh and continuing to decline.

The past and forward pricing curve for lithium-ion batteries — similar to the historic curve seen in the photovoltaic (PV) solar industry — has dropped rapidly and consistently over the past 10 years. Assuming a forward pricing curve for lithium-ion consistent with historic PV panel pricing, it is conceivable that lithium-ion pack prices could fall below $100/KWh by 2024 and under $70/KWh by 2030. Unless there are breakthroughs in mining, the 2030 price point is approaching the cost of raw materials and will be driven predominately by demand for electric vehicles (EVs) as they become more predominant over internal combustion vehicles.

BATTERY SAFETY IS A REAL ISSUE

Battery safety is a significant and justifiable concern in the industry.

With 29 confirmed lithium-ion fires in South Korea as of year-end 2019, the South Korean government issued a moratorium on new storage projects and initiated a root cause investigation that lasted five months and covered 23 of the 29 fires. The investigation determined that poor battery integration was a leading contributor to the fires. Examples of poor integration include lack of DC ground fault protection, poor humidity control, water ingress, module damage during installation, and faulty control systems.

The predominant battery cathode chemistry associated with the South Korean fires is lithium nickel manganese cobalt oxide (NMC). Alternative cathode chemistries are commercially available, including lithium nickel cobalt aluminum oxide (NCA) and lithium iron phosphate (LFP). While the initial government report did not point to battery chemistry or defects as a root cause, it is certainly a common thread that runs through the installations where fires have resulted. Though LFP has fewer installations worldwide than the cobalt-based chemistries, it has a good safety record. LFP, however, has a much lower energy density than the cobalt-based chemistries, which makes it less suited for applications where space is at a premium.

One of the drawbacks of cobalt chemistries is the cobalt itself. Cobalt is expensive and drives up the raw material cost of the battery. About 60% of the world's supply of cobalt is mined in the Democratic Republic of Congo (DRC) which has a history of human rights abuses involving child labor in its mining industry. Although a small percentage of the total cobalt mined in the DRC is associated with child labor, there is an increasing focus on sourcing conflict-free cobalt, which can increase cobalt pricing and drive manufacturers to reduce the cobalt content in batteries. Unfortunately, battery cell manufacturers must grapple with the fact that decreasing cobalt content results in inherent instability and subsequent safety issues such as thermal runaway.

THERMAL RUNAWAY

Lithium-ion battery fires are typically the result of thermal runaway, a process caused either by battery cell manufacturing defects or some form of battery abuse. Generally, there are three forms of battery abuse: electrical (over-charging, for example), mechanical (puncturing or dropping the battery module, for example), or thermal (heating a battery beyond its temperature range, for example).

When one battery cell is abused and begins to thermally run away, the heat it produces thermally abuses adjacent battery cells and that process quickly spirals out of control. This process often results in a total loss for the batteries located near the original abuse point.

CONVENTIONAL SUPPRESSION INEFFECTIVE

Most typically, battery storage containers have been outfitted with a clean agent or aerosol-type fire prevention system. These have been shown to be very ineffective at controlling the thermal runaway process.

Because thermal runaway is an exothermic process, the associated battery cells must be cooled below their thermal runaway temperature to stop the process. Otherwise, the runaway will continue to spread to adjacent cells. Unfortunately, gaseous fire agents have not been shown to have any appreciable cooling effect. They also typically require both heat and smoke to actuate and it is likely that multiple battery cells have already gone into thermal runaway before enough heat is generated to trigger the heat sensor. At this point, without the ability to cool the battery cells, it is too late to effectively stop the process.

Traditional water-based suppression systems also present problems. These systems are typically designed with sprinkler piping and heads routed above the racks. This means that the sprinkler system, once activated, is only effective at reaching the very top module in each rack. Since thermal runaway events can result in flames emitting from one or more sides of the module (and not necessarily the top), sprinkler head placement becomes critical. Water-based systems must cool the module at the precise location experiencing a thermal event and may require spraying all six sides of the module to be effective.

OFF-GAS DETECTION MAY BE BEST ALTERNATIVE

When a lithium-ion battery cell is damaged, it will typically release volatile organic compounds (VOCs) as a result of electrolyte vaporization and a subsequent rupture of the cell packaging. If the abuse continues, smoke and heat follow shortly thereafter. The period between off-gas release and smoke beginning can range from seconds to minutes depending on a variety of factors and typically precedes other early warning signs, including cell voltage and temperature excursions, by minutes.

Off-gas detection systems are commercially available that can sense the VOCs released as a result of cell damage. These systems consist of small sensors placed on the battery racks and wired back to a controller that determines the presence of abnormal levels of VOCs. Upon detection of an off-gas event, the system can initiate an alarm and shutdown of the battery. By detecting the damage before the thermal process begins, off-gas detection systems may be one of the only external protective devices available today that can effectively prevent thermal runaway.

ENVIRONMENTAL CONCERNS

When water has been used to fight lithium-ion battery fires, runoff has later been tested and found to contain a number of hazardous substances including mercury and other heavy metals. At this time, there are no known U.S. federal standards that address fire event water runoff from lithium-ion batteries and state/local standards are inconsistent at best.

Without clear regulatory guidance, it is important that the industry develop more coordinated and cohesive methods for preventing runoff of hazardous materials at large-scale lithium-ion battery installations. It is recommended that any firewater runoff be tested before being conveyed to any public sanitary or wastewater system.

EDUCATING FIRST RESPONDERS

When considering the installation of a new lithium-ion energy storage facility, one of the first contacts should be with the local fire marshal or other authority having jurisdiction (AHJ) to discuss the fire risk.

According to the hazardous materials code under National Fire Protection Association (NFPA) Section 400, lithium-ion battery fires are considered a Class D (Metal) fire. Thus, different firefighting techniques are required, as conventional tactics might make a lithium-ion fire worse. Therefore, it’s vitally important to proactively communicate with fire departments, talking early and often so they understand the hazards of these unique systems and can adequate prepare for any issues.

A prudent additional step would be placing signage on buildings or containers giving firefighters information about the types of batteries inside and the types of chemistries associated with those batteries.

The signage should warn of the presence of lithium-ion batteries and should provide basic information about the battery such as chemistry. The signage should also include contact information for obtaining any additional information that may be needed such as the battery manufacturer, system voltage, potential off gases, and other hazards associated with the installation.

THE FUTURE IS BRIGHT NONETHELESS

Even with all the cautions, it must be noted that lithium-ion battery thermal runaway is relatively uncommon, with the vast majority of battery installations operating as intended.

With lithium-ion battery technology advancing quickly, the industry must develop designs and strategies at the very earliest stages of the project to mitigate risks associated with battery hazards. Doing so as the project develops or as an afterthought may be too late to effectively pivot to new technology or techniques for managing battery safety. This is especially critical considering the size of the projects currently under development and construction.

Finally, we must anticipate that some failures of these systems will occur. Even with millions of cells performing exactly as designed, a single cell defect can trigger an event. Ultimately, early detection and then quick shutdown of the entire system might be the best technique available to limit widescale damage. And when issues do occur, it is important to see that that first responders are aware of the unique hazards associated with lithium-ion batteries and can respond appropriately.

BIOGRAPHY

CHRIS RUCKMAN, PE, is energy storage director in the Energy Group at Burns & McDonnell, where he oversees the development of energy storage solutions to meet growing electrical grid challenges. An electrical engineer with more than 25 years of experience, Chris combines a passion for sustainable solutions with his deep technical understanding of the utility industry to develop safe, reliable, and cost-effective energy storage solutions. Chris is an active member of the IEEE PES Power System Relaying Committee, served as vice chairman for the Synchronous Generator Protection Tutorial and currently serves as chairman for a working group investigating black start generation protection complexities. Chris earned a Bachelor of Arts in physics from William Jewell College and a Bachelor of Science in electrical engineering from the University of Kansas.

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