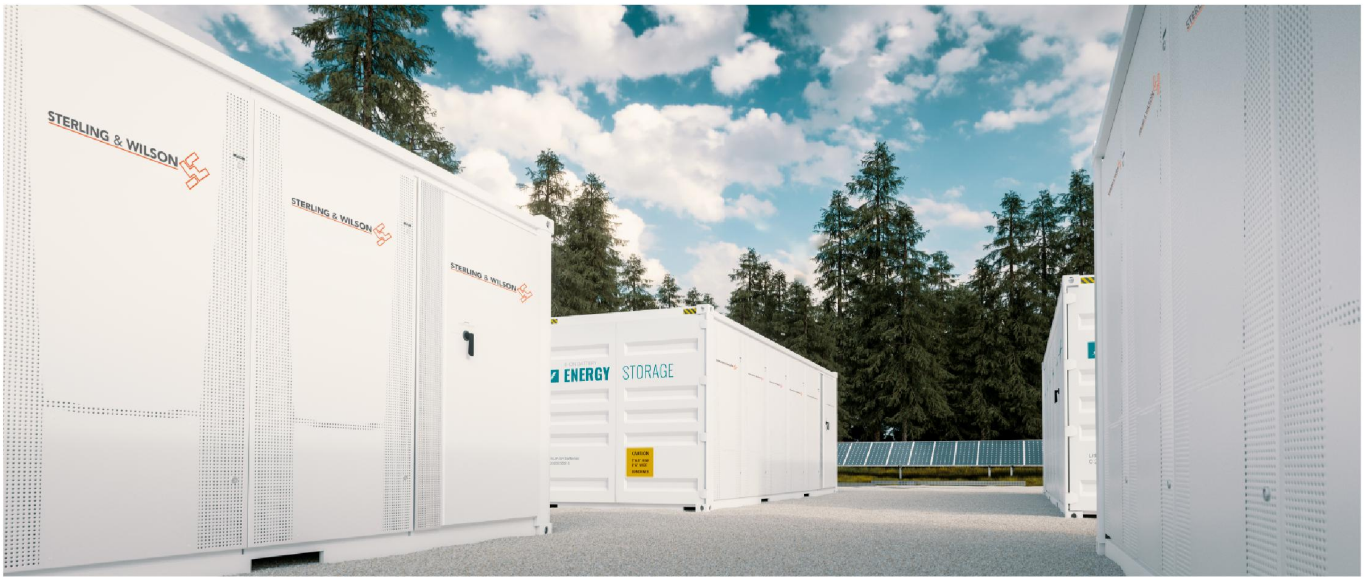
PREVENTING HAZARDS:
TOWARDS SAFER BATTERY ENERGY STORAGE METHODS



The need for energy storage

Battery energy storage systems (BESS) are forecasted to play a vital role in the future grid system, which is complex but incredibly important for energy supply in the modern era. Currently, Li-ion batteries are the most widely deployed BESS for a wide range of grid services because they offer high energy efficiency, long cycle life, relatively high energy density and, in tandem facilitate modularization, and flexible installation. While they offer many advantages over counterpart technologies, Lithium-ion batteries also introduce some potential fire hazards that must be managed.

Recent battery fires

A grid-scale battery fire in West Valley, Arizona, in April 2019 caused large-scale destruction. Reading into DNVGL's findings, it seems that a defective cell (in an ensemble of thousands) underwent lithium metal deposition and abnormal dendritic growth that eventually caused piercing of the cell's separator, resulting in an internal short-circuit. This kicked off a chain of exothermic chemical/ electrochemical reactions that spontaneously increased the temperature of the cell.

The extra heat caused a positive feedback cycle generating a tremendous amount of heat, leading to an uncontrollable rise in temperature (thermal runaway), resulting in a fire. The fire propagated to nearby cells, eventually destroying a rack. The accumulation of unvented explosive gas then caused a blast, injuring firefighters and further destroying the battery system.

Only a few weeks ago in **April 2022,** there was another fire in Arizona, again with a battery system.

While these incidents are associated with energy-dense nickel-manganese-cobalt-oxide (NMC) cells, fire concerns are by no means restricted to NMC cells.

In **April 2021,** a fire at a 25 MWh lithium-iron-phosphate (LFP) based battery system in Beijing claimed the lives of two firefighters. The causes of fires are also not restricted to inherent cell defects; indeed, using a battery system outside of its specified operational boundaries (temperature, charge/ discharge rate, upper and lower voltage setpoints, etc.), poor thermal management, operational negligence, and even improper systems integration can cause fires. For example, a liquid coolant leak at 300MW/ 450MWh electric storage facility in Australia instigated a thermal runaway event.

In conclusion, Lithium-ion batteries pose a fire risk, albeit small, considering the frequency of occurrence, at least at grid scale. In fact, whenever we concentrate a large amount of energy – regardless of technology – there is a risk that an uncontrolled release of the energy could result in a fire or explosion. Given that Li-ion batteries are the preferred option for grid-scale storage today, our primary focus is the prevention and containment of fires.

In this regard, there are several safety features that we deploy:

1. Rack level battery protections

As a systems integrator, we typically purchase battery racks from battery OEMs and then wrap them into an enclosure with balance of system. We would typically demand that our battery suppliers (OEM) offer a battery management system (BMS) for each battery module within the rack. BMS is a critical safety feature which ensures that the battery is not abused, i.e., operated outside of its operational boundaries. If BMS detects that the module is degraded or abused, it manages the risks using mitigation measures, such as electrically isolating or inhibiting one or multiple cells.

The BMS monitors and regulates temperature across the module by opening and closing various valves to maintain the temperature of the overall module within a narrow range. This is done with minimal thermal gradients across large format cells and ensures optimal battery performance and minimal degradation. Depending on the battery OEM, the BMS will also actively balance cells in the module, which allows for a higher degree of control and protection.

Beyond that, at the rack level, we typically want a master Battery Protection Unit (BPU) that carries out a similar function to the BMS. In addition, rack-level electrical protection would also feature a main DC circuit breaker with shunt-trip functionality, a control power circuit-breaker, DC fuses (with status indicators), charge/ discharge contractors, diodes, and an emergency stop.

2. Gas-detection systems as a preventive measure

Conventional methods of cell failure detection are usually based on voltage, current, or cell surface temperature measurements. In the event of an internal short-circuit, a significant voltage drop is normally detected before thermal runaway or when the safety vent blows out of the top of prismatic cells to allow for venting. Voltage-based methods work well for single cells, but when a large number of cells are connected in parallel, the fault voltage signal is suppressed.

Off-gassing is often a precursor of thermal runaway and thus offers a more reliable indicator for an impending thermal event. Results from independent testing suggest, on average, there are 11-12 minutes between detection of vent-gas and thermal runaway. The composition of battery vent gas during a heating event includes CO_2, CO, H_2, and organic compounds. The precise composition that is vented will depend on cell chemistry (composition of cathode, electrolyte, and anode) and state of charge (SoC).

While organic compounds can be detected in most cases, gas detection based on organic compounds may pose reliability challenges due to the fall in concentration after exposure to air. On the other hand, CO_2 can be detected in significant concentrations in all cases, regardless of cell SoC and cell chemistry.

For Sterling and Wilson Renewable Energy's (SWRE) LFP-based BESS projects, we use a combination of CO_2 and H_2 sensors as these gases release relatively in more quantity. Detection of abnormal amounts of CO_2 or H_2 thus acts as a trigger for us to take preventive action against thermal runaway.

3. Automatic fire suppression systems

If preventive measures are unsuccessful and a damaged cell ignites, measures must be put in place to contain the resulting fire and minimise the potential for propagation to other cells. In addition to compartmentalising racks, it is usual to adopt an automatic fire suppression system with an extinguishing agent such as HFC-227ea, Novec 1230, Stat-X, or water mist. The various options have pros and cons, detailing of which is beyond the scope of this note.

SWRE's experience is that the choice of extinguishing agent will depend on many factors, including effectiveness as a suppressant as well as coolant, site constraints, impact on the environment, potential cost and availability of replacements. For Australian projects in remote places, we would consider Novec 1230 due to better environmental credentials compared with HFC-227ea.

4. Safety features like pressure release valves

We recognise a significant amount of damage to grid batteries that occurs due to propagation of thermal runaway and the accumulation of unvented explosive gas, as evidenced by the April 2019 fire in Arizona. Therefore, where SWRE integrates racks, we typically add pressure relief dampers in the enclosure design. This facilitates venting and thereby reduces pressure and accumulation of combustible gasses.

Battery regulations are all about safety

There are several new and recently revised standards relevant to the design and deployment of BESS systems, which SWRE supports. These include UL 9540 and UL 9540A standards. The UL 9540 is a safety standard for BESS and related equipment – including requirements for safety, functional safety, fire detection, suppression, containment, environmental performance, and more – that is intended for grid connection (or standalone application). The UL 9540A is a test method for evaluating thermal runaway propagation. While it does not result in a certification, it provides valuable data to OEMs that help determine if their product meets regulations. We require our battery suppliers to be compliant with UL 9540A, UL 1973, IEC 62619, and IEC 63056.

An exciting road ahead

In grid applications, where lithium-ion batteries (LiB) are pushed to their limits of power and energy delivery (usually multiple deep cycles at maximum power), the prevention of thermal runaway is vital. Beyond the preventative and containment measures discussed above, there are key technological innovations emerging in the market to address thermal runaway, including novel positive temperature coefficient materials, self-healing polymer electrolytes, and hybrid liquid-solid-state electrolytes. At systems level, we are seeing increasingly more sophisticated BMSs that figure out employ real time data to accurately predicting temperature gradient evolution.

Mist cooling is also being promoted as an effective way to achieve uniform temperature inside the battery rack without the need for pumps to circulate a coolant. Advances in technologies facilitating LiB safety are continuously evolving which will only act to pronounce penetration of this vital technology. Fire safety understandably is a concern, but with necessary safety checks put in place – in the design, construction, execution and operation stages – BESS is poised to be part of a safer and greener future. The road ahead is exciting indeed!