Stopping thermal runaway six minutes before it starts

Fire safety | Crucial to clean power generation, battery energy storage systems need advanced fire protection. Steve Kenny, general manager for Advanced Fire Detection at Honeywell Building Technologies talks about why the detection of off-gases is an important line of defence.

Credit: Honeywell Building Technologies.

Smoke and off-gas detection monitoring sensors, mounted on top of lithium-ion battery racks.

Wind and solar farms, microgrids, data centres and telecom facilities have at least one thing in common: they rely on battery energy storage systems (BESSs) made of thousands of lithium-ion (Li-ion) cells. BESSs not only play a critical role in the transition to renewable energy and smarter power grids but also have become a key component of data centres and telecom hubs – both drivers of economic vitality worldwide.

The global market for utility-scale BESSs, valued at US$2.9 billion in 2020, is expected to grow at a CAGR of 32.8% from 2020 to 2025, reaching US$12.1 billion by 2025. If you factor in uninterruptible power supplies (UPS) for data and telecom centres, vehicle charging stations and all other energy storage applications, that number more than doubles. The total global energy storage market is projected to grow from US$7.8 billion in 2020 to US$26.8 billion in 2028.

Why have Li-ion cells become the enabling technology? They're affordable; they offer high energy density for their size and weight; they hold their charge longer; they're less prone to self-discharge than other battery types; and they require little maintenance and no periodic discharge.

Yet for all their advantages, Li-ion cells have vulnerabilities. For one, they require complex battery management systems (BMSs) to keep them operating within safe parameters of voltage, temperature and charge. If managed improperly or subjected to abuse, batteries can fail, resulting in off-gassing, excessive heat generation and if the electrolyte in the cells ignites, it can quickly escalate into a catastrophic, often explosive fire, that is extremely hard to extinguish (thermal runaway) that can spread to surrounding cells in an accelerating domino effect.

Three stages of battery failure

- Abuse factor: Electrical, thermal or mechanical abuse can potentially lead to thermal runaway. Electrical abuse occurs when the battery voltage limits are exceeded during charge or discharge. Because numerous cells charge or discharge simultaneously in a BESS, risk of individual cells sustaining electrical abuse increases. When operational temperature exceeds the batteries' heat specifications, it results in thermal abuse. Mechanical abuse refers to physical damage such as a crush, indentation or puncture.
- Initial cell venting (Off-gas): If the abuse factor continues, the battery liquid electrolyte will convert to gas, which will cause internal pressure build up inside the battery, exerting enough force to open a pressure relief vent or rupture the battery seals. This released gas is distinctly different than the release of gases at thermal runaway and often occurs several minutes prior to thermal runaway.
- Thermal runaway: With increasing internal battery temperature, the separator will melt down and rupture releasing smoke and igniting the electrolyte solvent. Gases emitted at this stage often include CO, CO_2 and combustible gases. The resulting fire can produce temperatures exceeding 1,000ºC (1,832ºF) and spread to surrounding cells causing them to go into thermal runaway leading to a total system failure.

BESS fires are a global concern

Thermal runaway is not a hypothetical scenario. In the last five years, major BESS fires have made the news worldwide. Between August 2017 and April 2019, authorities in Korea investigated 23 BESS fires, prompting them to suspend operations at numerous facilities as well as commissioning of new BESSs. A 6MW BESS in Europe, still undergoing commissioning, was declared a total loss following a November 2017 fire.

In April 2019, four firefighters sustained serious injuries while battling a fire at a 2.16MW Li-ion BESS in Arizona. At the height of the blaze, crews measured dangerously high levels of hydrogen cyanide gas and carbon monoxide. Fire crews in the UK responded to a September 2020 fire at a 20MW grid-connected BESS, which took them nearly 12 hours to extinguish and blanketed surrounding neighbourhoods with toxic smoke.

BESS hazards challenge conventional technologies

A large-scale energy storage facility requires a battery management system (BMS) to monitor voltage, current and temperature and prevent abuse of the batteries, but relying on a BMS as the only layer of defence against thermal runaway is risky. For one, a BMS can't resolve single cell temperatures or voltages. Even with a temperature sensor on every cell, there can be hot spots that go undetected.

Conventional technologies such as smoke and fire detection, CO, CO_2, lower explosive limit (LEL) monitoring often make up part of a comprehensive BESS safety solution. Smoke and fire don't typically develop until thermal runaway has already initiated, so these systems would not engage until it was too late to halt the chain reaction. CO, CO2, LEL often don't occur in detectable concentrations until thermal runway.

In short, these technologies are reactive to thermal runaway rather than proactive in forestalling. Even if a single cell has reached the point of emitting smoke or fire, it may well be too late to stop the reaction from spreading to surrounding cells.

Fire suppression: too little, too late

Suppression is a BESS's last line of defence against fire when all preventive measures have failed. Yet, according to a recent study published in the Journal of the Electrochemical Society (JES), none of the primary suppression methods has been proven entirely effective in containing BESS fires.

Smothering technologies have little effect, as oxygen is often already present in battery components. Cooling systems that apply a continuous water mist to cool the battery are more effective but can cause short circuits, further propagating thermal runaway. Chemical suppression, including conventional fire extinguishers, can't arrest thermal runaway and can only suppress open flames outside the battery.

The JES study also found that, even after initial suppression, the exothermic chemical processes inside the cells often continue, creating a high risk of reignition. A 2019 DNV study that analysed different shipboard suppression systems to assess their effectiveness against BESS fires found there was no 'silver bullet' solution.

Initial venting (off-gas) detection gets out in front of thermal runaway

Detecting the early signs of failing Li-ion batteries is critical to enable operators and shutdown measures to respond proactively in time to prevent thermal runaway and catastrophic, often explosive fires.

Another study from DNV tested three technologies to assess their response times in detecting early signs of potential thermal runaway: off-gas sensors, cell voltage sensors and lower explosive limit sensors, which detect dangerous levels of combustible gas or solvent vapour. Of the three types, off-gas detectors displayed the highest sensitivity and accuracy. They averaged less than 10 seconds' response time after off-gassing started and 6 minutes 11 seconds before thermal runaway commenced. Neither the LEL nor voltage sensors activated until after thermal runaway had initiated.

The results also showed that shutdown measures combined with off-gas detection effectively prevented thermal runaway. Once off-gassing was detected, the battery system was electrically isolated, which prevented the cell temperature from increasing and thus stopped the propagation to adjacent cells.

Tailoring off-gas detection to BESS parameters

Detection of the initial venting (off-gassing) in a BESS, though, presents certain caveats. Such a system can't just be procured off the shelf because each BESS poses its own challenges, as noted in a 2020 UL study. The solution must be designed to a BESS's unique configuration – its geometry, volume, cell type, spatial layout and air-flow patterns. With these data in hand, designers can optimise the location and number of sensors to deliver the earliest detection using the least number of sensors.

Off-gas detection gives customers access to the first indication of failure and serves as a barrier to potential thermal runaway and catastrophic loss. By implementing this technology in renewable energy utilities, microgrids, data centres and telecom facilities, BESS owners can protect their people, assets and irrecoverable data – not to mention firefighters and other first responders. At the same time, they can avoid costly downtime, increase their resilience and help advance the transition to renewable energy.

Off-gas release	-381
Off-gas sensor	-371
Thermal runaway	0
Cell voltage	+7
LEL Sensor	+28

Source: DNV 2019 study, "Technical reference for Li-ion battery explosion risk and fire suppression".

Five ways to optimise off-gas/smoke detection in data centres

Fires pose a real threat to data centres, where they can spread quickly, putting employees at risk while destroying expensive hardware and irreplaceable data. With profitability, reputation and business continuity on the line, deploying an advanced, very-early-warning system that can detect the first sign of a potential battery failure is critical. Here are five design tips that can help protect people and mission-critical infrastructure while simplifying fire safety management.

- Assess the Risks: Start by focusing on three key areas to assess the factors contributing to fire risks: electrical systems, mechanical systems and administrative practices. Electrical systems can malfunction, overload or degrade over time. Mechanical system risks often stem from a malfunction in the HVAC system, generator or fuel lines. Administrative factors such as human error, poor housekeeping or inadequate storage protocols can also contribute to fire hazards.
- Know Your Environment: Understand the environmental challenges presented by data centres and telecom infrastructure to enable effective off-gas detection for Li-ion BESS areas and smoke detection. Cooling configurations, air flow characteristics, air temperatures and pressure differentials can vary dramatically from one area to another, and they all have a direct impact on the propagation of battery electrolyte vapours and smoke. In addition, data centres often house high security areas where access is limited, making installation and maintenance of off-gas and smoke detectors difficult. Other factors such as existing containment strategies, high air flow and complex ceiling configurations will determine the choice of off-gas and smoke detection technologies and location of the devices.
- Understand the Structural Challenges: Factor in ceiling height, concealed spaces, room geometry and equipment dimensions to understand how they'll affect air flow patterns, ventilation and, ultimately, the way off-gas or smoke can be detected. Certain areas may not be covered by fire safety standards or may require enhanced protection therefore a bespoke performance-based design (PBD) should be adopted.
- Keep It Accessible: Understand accessibility challenges when designing an off-gas or smoke detection system. System accessibility enables quick response to potential alerts as well as easy installation and maintenance. Awkward locations such as raised floors, ceiling voids or underground vaults can make system maintenance a tedious task that can lead to downtime or even security breaches in secure areas. Luckily, you can address this challenge early on by selecting control systems that can be mounted in easy-access areas, with the network of sensors or sampling network feeding information from hard-to-reach locations.
- Follow Regulations: Adapt to specific building regulations, if available, or follow an accepted Performance Based Design to deliver proactive early warning. Conducting an appropriate off-gas and/or smoke test during commissioning is a must, especially in critical infrastructure environments like data centres. Trusted manufacturers can advise on how to design a solution that checks all the boxes and goes beyond best practices to enhance safety.

Author

Steve Kenny is general manager of Advanced Fire Detection solutions for Honeywell. He has 27 years' experience in the thermal process and IoT industries. Steve is based in Rolle, Switzerland.