

---

## Early Detection of Hazardous Conditions in Energy Storage Systems

---



## Early Detection of Hazardous Conditions in Energy Storage Systems

With increasing deployments of very large battery systems in stationary applications ranging in size from hundreds of kilowatt-hours to hundreds of megawatt-hours, safety has never been more important. While hazard consequence mitigation such as automated fire detection and suppression systems provide ways to limit damage and harm after a thermal event occurs, the battery management system and advanced controls will become the key to detecting defective battery cells and modules before they become a problem. As large stationary battery systems are typically under continuous monitoring, a battery management system (BMS) combined with intelligent algorithms can help detect and prevent hazards from escalating into a thermal event, alerting operators to shut down and quarantine potentially dangerous batteries from continued operation.





## Introduction

As the electricity grid begins to add greater amounts of stationary energy storage, much of it based on lithium-ion battery systems, individual energy storage system sizes are also increasing from hundreds of kilowatt-hours to hundreds of megawatt-hours. Add to this the fact that many installations' proximity to people and buildings is becoming increasingly common, and the safety of large energy storage systems becomes critical. In fact, the industry is seeing a greater number of accidents including a fire and explosion in Arizona in April 2019 with a major utility company, an incident in Belgium in 2017, as well as dozens of fires in South Korea in 2018 and 2019, all related to stationary battery systems. While these most recent events were all related to lithium-ion, in the past there were also fires involving other types, including very mature technologies like lead acid batteries (2012, Oahu, Hawaii) and specialty stationary technologies like sodium-sulfur batteries (2011, multiple cases in Japan).



## Battery Safety Basics

In general, lithium ion batteries are safe for daily use in a variety of applications including portable devices like smartphones or laptops, to automotive with hybrid and full electric vehicles, and more recently the megawatt-scale systems deployed in the grid. However, the scale of the hazard increases with the size of the battery system. Thus for larger systems like those deployed in the grid, battery safety becomes very important.



Portable Devices  
5Wh-80Wh



Personal Electric Mobility  
150Wh-800Wh



Home Energy Storage  
4,000Wh - 20,000Wh



Electric Vehicles  
20,000Wh - 100,000Wh



C&I Energy Storage  
100,000Wh - 800,000Wh



Utility-Scale Energy Storage  
Over 1,000,000 Wh

As long as lithium ion batteries are used within their allowable operating limits, they are typically very safe. The three critical parameters to monitor are:

1. Voltage
2. Temperature
3. Current

These three parameters can be used to determine the condition and state of the battery. In addition, the way these parameters change over time, with respect to each other, and compared against cells undergoing similar operation provide a rich set of data from which to derive additional insights into cell operation.

## The Battery Management System

The Battery Management System (BMS) is a key component ensuring safe operation of battery cells. The BMS can continuously monitor critical parameters of cell voltage, temperature, and current for excursion beyond safe operating limits. In energy storage systems such as those used in stationary applications, the BMS typically has control of high power switches called contactors that connect and disconnect the battery to external power sources and loads. If the BMS detects voltage, temperature, or current levels outside safe operating parameters, it can take an active role in safety by disconnecting the batteries from the external power that could be causing unsafe conditions. Since the criticality of the actions of the BMS for safety is high, it is prudent to ensure that the BMS is certified to operate under appropriate Safety Integrity Level (SIL) environments as defined by industry functional safety standards such as IEC 61508.



While the BMS can stop operation under hazardous voltage, temperature, or current conditions, batteries must first exceed certain limits before the BMS can take action and disconnect the power source or load that may be causing excursion outside allowable operating parameters. A better approach would be to detect weak batteries or cells, and identify them for inspection at the next scheduled maintenance interval, perhaps taking them offline preemptively to eliminate any external stimulus from forcing them into unsafe conditions. NEC has developed advanced algorithms, deployed in its AEROS® software controls platform, to serve as an early warning system to prevent batteries from impacting operational reliability, and even help identify individual batteries or cells that may be prone to becoming hazardous.

### Early Detection of Hazardous Battery Conditions: A Case Study

In 2017, NEC Energy Solutions installed one of its GSS® grid storage solutions for a customer for the purpose of performing ancillary services. The batteries used in this installation operate on a continuous basis, helping to balance the grid's frequency and stabilize the grid. Each energy storage rack has their own BMS to monitor continuously every battery within the energy storage rack for unsafe conditions.

Along with continuous monitoring, NEC's AEROS® software suite employs advanced anomaly detection algorithms to identify weak battery modules and cells for removal and replacement to minimize downtime. These help operators and service personnel ensure the reliability of the system is as high as possible. These same algorithms were instrumental in identifying weak batteries that may have resulted in a catastrophic failure, before it happened.

In 2019, AEROS® routine monitoring and weak module analysis uncovered a battery module that behaved differently from the others in the energy storage rack in which it was located. While the parameters did not exceed any safety limits, the rack was nevertheless marked for service at the next maintenance interval. To prevent a larger system foldback (reduction in performance), the rack was removed from service by opening its contactors and disconnecting it from the rest of the system. Due to NEC's system design, the removal of this rack did not impact the overall performance of the energy storage installation. It is important to note once again that the battery modules identified **did not exceed safety limits at this time**.

When the NEC service team removed the battery module identified by the AEROS® Command weak module detection algorithm, they discovered that it exhibited a noticeable bulge. Bulging or swollen battery cells are a strong indicator of failure of the cell, potentially in a hazardous manner. Further analysis of the module confirmed the presence of swollen battery cells causing the bulging of the module. If left to operate, these bulging cells may have resulted in a catastrophic failure and possibly a thermal runaway event that could have led to a fire and damage to the surrounding battery system inside that container.

While this case was illustrative in finding battery modules with physical evidence of possible hazard, it is not the only historical finding of potential safety issues by the NEC energy storage system design. In fact, several instances of issues have been detected by various preventative safety features included in NEC Energy Solutions grid energy storage installations. These instances include detection of ground faults by NEC's ground fault prevention features, which if left unattended and in operation, could have led to a short circuit, a high voltage arc, and possibly fire. It is important to note that while the battery cells are the most focused-on component of any energy storage system with respect to safety considerations, the high voltage and high power nature of the rest of the system can cause safety issues. Power conversion systems (inverters), supporting monitoring circuitry such as battery management systems or module electronics, and all elements of the high voltage circuit including contactors, fuses, cabling, busbars, and conductor terminations (lugs or connectors) can cause safety issues. The best energy storage system designs consider all of the components and take a fully integrated system safety approach to minimize hazards.



Swollen cells discovered inside the battery module

## Conclusions

While mitigating hazardous consequences like thermal runaway, fire, and explosion are important to employ, **prevention and early warning** are more powerful techniques to minimize or even eliminate catastrophic failures. Functional safety certified battery managements systems, combined with advanced weak battery detection algorithms can potentially detect and predict failure before it happens. Pre-emptive removal of potentially hazardous batteries can greatly reduce the risk of thermal runaway. Hazard prevention combined with hazard consequence mitigation like automated fire suppression systems, are the key to safe reliable operation of large-scale energy storage systems.