Single Cell Li-Ion Battery Failures: **Impact and Lessons Learned**

Introduction

With the advancement of technology in modern systems, there has been an increased demand for electrical storage to power these systems. In commercial, automotive, and aerospace applications, this demand for additional power storage has driven the adoption of high-capacity energy storage systems (ESS). These systems most commonly rely on Lithium Ion (Li-Ion) Batteries. Li-Ion batteries have several key advantages, such as energy density and good cycling performance. However, Li-Ion batteries are vulnerable to thermal runaway if damaged. A thermal runaway in a single cell can lead to a cascading failure and major fire event. To prevent such incidents, there has also been a rise in testing solutions to identify thermal runaway risk upfront.

One such thermal runaway event occurred in 2013, impacting the aviation industry. This event caused significant disruption to the companies and consumers involved. Rather than the failure of the entire ESS, one cell within the system failed. This failure caused damage to the entire ESS and created a fire risk. As anyone who flies knows, fire on an aircraft is sub-optimal. By understanding this 2013 incident, we can see how robust testing can help prevent reoccurrence in new systems.

Incident Overview

In January 2013, two large commercial airliners suffered thermal runaways in their Auxiliary Power Units (APU). To assist with the startup of these APUs, Li-Ion battery packs were used to provide the starting power. During operation of the airliners, the Li-Ion batteries failed, causing thermal runaway. The NTSB launched an investigation, identifying the failure of individual cells in the pack as the initiation point (Section 3.2).

Impact on the Industry

The incident grounded 50 in-service aircraft. This led to significant disruption to both airlines and passengers. Despite the issue being with a single battery cell, the failure put the entire airliner at risk. An earlier such failure of Li-Ion batteries in 2010 caused the crash of a UPS freighter aircraft. In that incident, a shipment of batteries caught fire and eventually brought down the flight. These incidents are a clear demonstration of how quickly Li-Ion thermal runaways can become catastrophic. Li-Ion batteries are often used in ESS or battery packs, in close proximity to other Li-Ion cells. The heat from a single battery failure can damage the adjacent cells, pushing them into thermal runaway as well. Additionally, a failing cell can generate a tremendous amount of heat quickly. During their investigation, the NTSB found a failing cell could go from ambient temperature to over 500°F in under 30 seconds.

Because of these factors, traditional firefighting techniques struggle to deal with Li-Ion fires. This means a Li-Ion fire endangers not just the ESS, but the entire structure in which the ESS is installed in. This outsized impact of a small battery failure is not restricted to the aviation industry. In other incidents, entire warehouses, electric vehicles, homes, and buildings have been consumed because a single Li-Ion battery cell failed. This is why understanding how a battery fails is so important, and why safety testing is vital in preventing incidents from occurring.

What Lessons Can We Learn from This

During their investigation of the 2013 event, the NTSB had 11 findings related to the incident. Of these, there are 5 findings in particular that can help guide modern development of Li-Ion battery systems.

Why We Identify Cell Thermal Stability

During the NTSB investigation, testing was done on several Li-Ion battery cells. This testing was to understand the kinetics of a thermal runaway event. They noted in finding Number 6 the importance of how “determining the initial point of self-heating in a Li-Ion cell is important in establishing thermal safety limits”. Li-Ion batteries produce heat for several reasons. As anyone with a cell phone knows, this can include during intended use such as charging. At some point though, the cell reaches a temperature where the components begin to break down. This decomposition releases additional heat and pressure, causing the battery to self-heat. Knowing this temperature is vital in ensuring the ESS system operates safely below it.

This raises the question; how do we identify safe operating limits? To safely operate a battery, we must know when damage can occur. To determine what conditions can cause damage, testing is needed. This testing forces a cell into thermal runaway in a controlled setting. While closely monitoring the cell's temperature, a Li-Ion battery is subjected to abuse. There are four kinds of abuse/damage that lead to self-heating:

Thermal abuse
(external heating
of the cell)

Physical abuse
(nail penetration
or crushing)

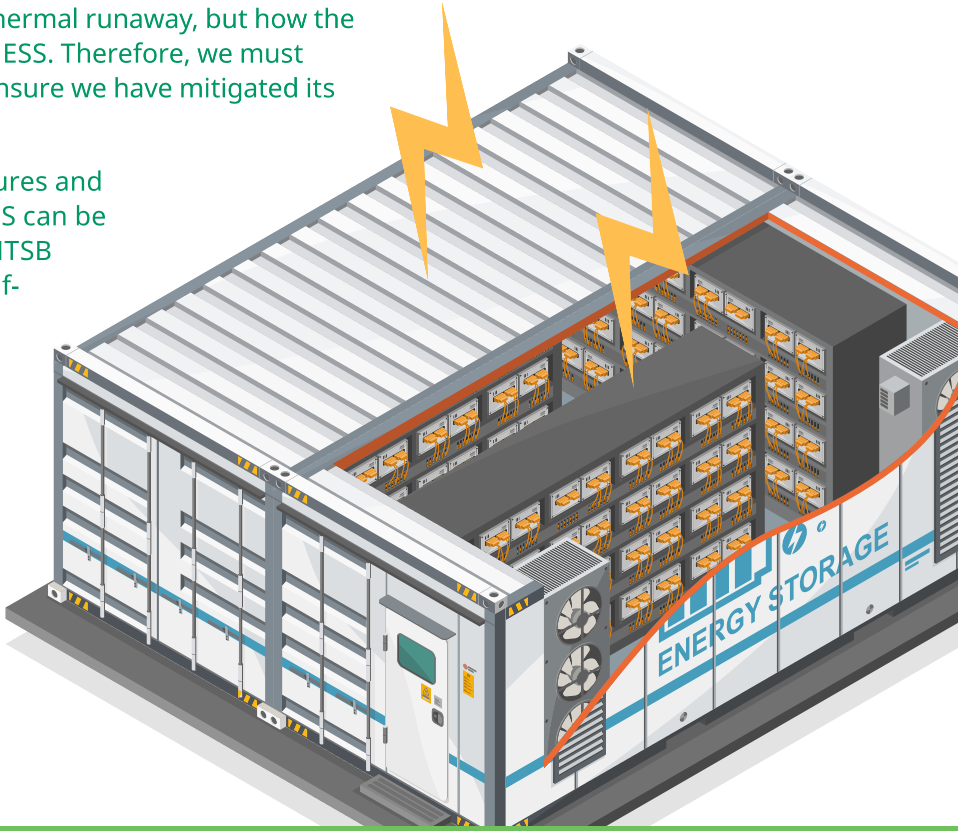
Electrical abuse
(causing
internal heating)

Manufacturing
defect

These tests are conducted in a highly sensitive calorimeter than can track temperature and pressure. DEKRA utilizes the EV+ Battery ARC out of the Process Safety lab in Princeton, New Jersey. This tool is purpose built for conducting these tests. The cell is loaded into a test chamber with thermocouples applied to monitor cell conditions, such as temperature and voltage. As the cell undergoes thermal runaway, data is collected to identify critical temperatures such as the onset of self-heating.

Beyond abuse of the cell, there can be flaws in the cell that led to thermal runaway. A defect introduced during the manufacturing process can trigger failure, even if the cell is not abused. The NTSB found that the thermal runaway was not initiated by electrical abuse, external heating, or physical damage such as a nail penetration (Finding 1). This is why thermal runaway testing is important, even if a cell is protected against abuse. Understanding not just what triggers thermal runaway, but how the runaway occurs is important for designing the ESS. Therefore, we must consider the impact of a thermal runaway to ensure we have mitigated its risk (Finding 7).

Armed with the knowledge of what temperatures and conditions can cause thermal runaway, the ESS can be designed to operate safely below them. The NTSB notes the importance of staying below the self-heating onset temperature. The temperature where self-heating begins is not the temperature where thermal runaway begins. As such, it is possible for a battery to self-heat without completely failing. Operating above the self-heating temperature can cause damage to the cell. While this damage isn't enough to cause a runaway, this can damage can be cumulative. Eventually this can lead to a thermal runaway despite not heating to the thermal runaway onset temperature. (pg 67 Mikolajczak 2011)



How Propagation Works

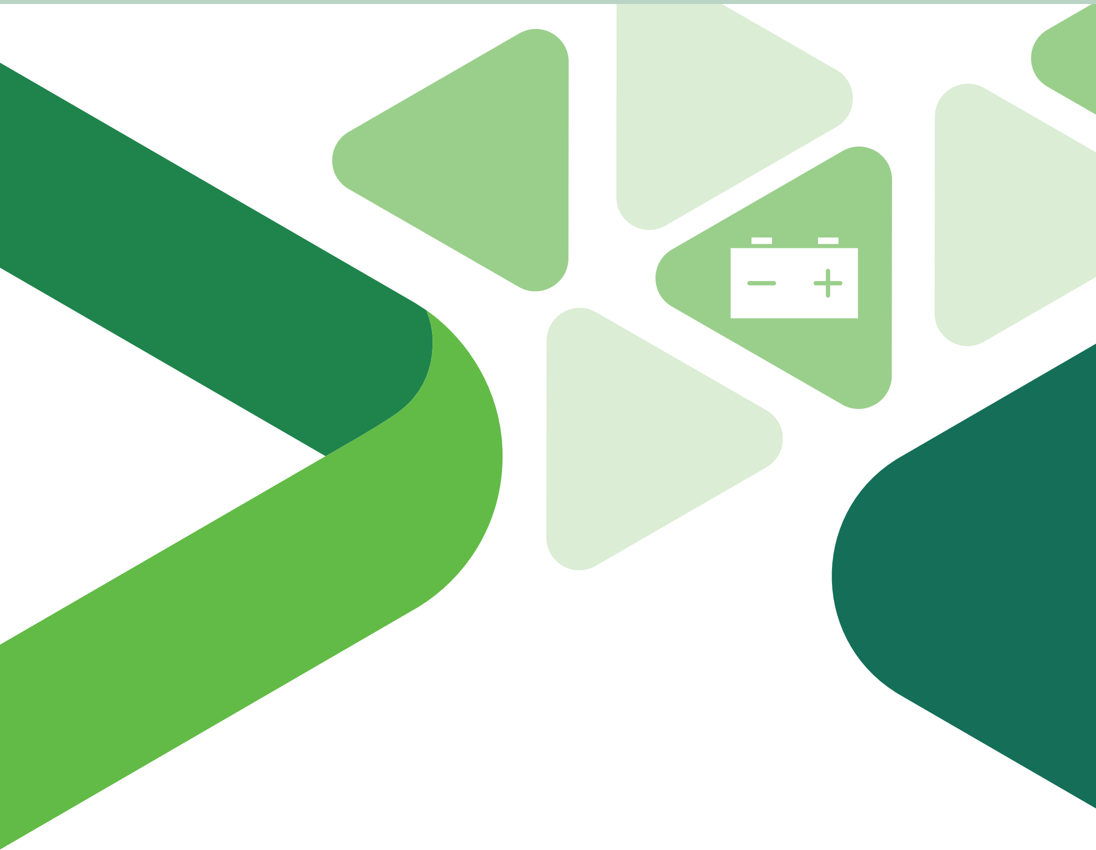
To obtain sufficient voltage and amperage for modern systems, ESS rely on multiple Li-Ion batteries working together in a single pack. As discussed previously, external heating of a Li-Ion battery can lead to the thermal runaway of that cell. This leads to one cell failure propagating to the adjacent cells. During the 2013 investigation, this is what the NTSB found had occurred during the incident (Finding 2).

- Li-Ion batteries rely on internal separators to prevent an internal short circuit from occurring. External heating can damage this separator, with separators melting around 250°F (this can vary depending on the separator used). Once this separator is damaged, thermal runaway is unavoidable.
- Modern standards have been informed by incidents such as this one and have developed testing protocols to look at propagation. Both UL9540A and SAE J2464 are used to evaluate battery packs to see how vulnerable they are to the propagation. However, both standards start at the cell level. This provides understanding how much energy a single battery releases, and how quickly that release occurs. With this data, ESS and battery packs made up of cells can have safety features implemented to try and reduce the risk of propagation due to one cell.

Conclusion

In the decade since the NTSB investigation was completed, the fundamental risks of Li-Ion batteries have not changed. If anything, modern battery components have enabled even higher energy density designs to become viable. These higher energy densities mean more violent failures during thermal runaway. As such, the lessons the NTSB learned during their investigation are still applicable to us today.

Energy storage continues to evolve with new technologies that may replace Li-Ion batteries. Until that time, we must rely on the standards that have been developed based on incidents such as this one. Additionally, we must continue to make data driven decisions backed up by testing. By testing our component cells, we can continue to improve our ESS designs and continue to produce increasing safer designs.



To find out more, get in touch with a DEKRA team member today.

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References and Resources

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