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Building Safe and Compliant Solar+Storage Projects

A Guide to Fire Testing for Battery Energy Storage Systems

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Executive Summary

Solar+storage project developers are operating in a dynamic regulatory environment where basic requirements can vary with time and location, leading to project delays and increased costs. In the worst-case scenario, lack of adherence to compliance requirements increases the risk of incurring loss of property, injury, or loss of life.

This white paper outlines the safety issues at stake in energy storage projects, and explains how fire testing to UL 9540A standards helps project stakeholders address safety issues and meet expectations of the authorities having jurisdiction (AHJs).

A Developing Market

The market for stationary energy storage systems (ESS) is still developing, so codes and certification testing requirements are changing rapidly.

Due to the fire and explosion risks associated with thermal runaway – a phenomenon that occurs when an uncontrolled rise in temperature causes battery cells to create more heat than they dissipate – **it is critical to procure safe equipment and to install and operate it correctly.**

Putting Safety First

No matter how a product is designed, where a project is located or which codes apply, developers are positioned for success when they put safety first from the start. **Smooth project execution begins with collecting data that builds confidence in ESS and meets the needs of AHJs.**

Developers can obtain this data through fire testing according to the UL 9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems. While the codes for energy storage projects tend to vary by geographic location and are evolving as the market expands, the codes listed below require UL 9540A:

- **International Fire Code (IFC):** Most states follow the 2015, 2018 or 2021 version of the IFC. IFC 2021 contains the most robust ESS requirements and is likely to achieve widespread adoption over time.
- **National Fire Protection Association (NFPA):** NFPA 1 includes ESS requirements and is adopted by fewer states, but those states are important markets for ESS. In November 2019, NFPA 855, a Standard for Installation of Energy Storage Systems, was published. This was a large consensus achievement in compliance requirements which are increasingly harmonized with IFC and NFPA 1.

Location-specific codes are also relevant. For example, New York City not only requires UL 9540A for all li-ion battery systems but also has additional safety requirements, installation conditions and operational parameters.

Understanding Fire Testing

In order to ensure that ESS are properly designed, installed and maintained, third party large-scale fire testing must be performed. There are three main benefits:

1. It provides developers and manufacturers with a more comprehensive understanding of their ESS which can be leveraged to improve system and product design.
2. It helps developers and asset owners validate battery manufacturers' claims on the intrinsic safety of their systems.
3. It generates empirical data for the design and installation of safety measures that mitigate risk should failure occur.

Fire testing (pictured above) reveals potential cell-level, module-level, unit-level and installation-level fire risks.

Meeting the Needs of Local Authorities and Fire Departments

Developers demonstrate their safety commitment to the local authorities and fire departments by providing them with the right data – especially when local authorities have limited experience with ESS. As more municipalities adopt national ESS codes and standards, it remains vital to provide reliable data that addresses the main concerns of AHJs: risk of fire and explosion events, the effect of smoke and chemical plumes on air quality, first responder safety and emergency response planning. Figure 1, below, provides an overview of these concerns.

Figure 1: ESS Safety Concerns

Fire

Thermal runaway in a single failing battery cell can quickly lead to a full-scale fire and propagate to nearby units or battery enclosures. Lithium-ion battery fires are extremely difficult to fully extinguish.

Explosion

Battery cells undergoing critical failure often release flammable gasses that can create explosive environments in a confined space (such as a battery enclosure). In the unlikely event of an explosion, blast pressures emanating from the enclosure may injure first responders and damage property.

Air Quality

Toxic gases released during a battery failure such as carbon monoxide, hydrogen cyanide and others may present safety risks to unprotected personnel in the immediate surrounding area, including first responders.

First Responder Safety

The primary concern of fire departments is always to ensure the safety of first responders, operations staff, and the general public. Proper training on the unique hazards of ESS failures and appropriate firefighting tactics is imperative to mitigating risk of injury and loss of life.

Emergency Response Plan

Emergency response planning and documentation are critical for first responders and subject matter experts. Providing site-specific emergency contacts and information on system controls, fire suppression systems, monitoring and alarm systems, potential hazards and response tactics ensures AHJs are prepared.

Worst-Case Scenarios: Lessons from Surprise, Arizona*

In 2019, a lithium-ion battery thermal runaway event and resulting explosion at an Arizona Public Service facility became international news because four firefighters were hospitalized for serious injuries. Inadequate fire safety controls within a battery rack caused cascading thermal runaway that was not effectively suppressed. Additionally, the fire department was not provided with sufficient data about the ESS on-site.

Data that could have protected the first responders would have been available if UL 9540A testing had been conducted by a reliable source. These types of incidents are rare, but they have outsize impacts, such as: injury and loss of life, property damage, lost revenues and public disapproval.

To prevent ESS worst case scenarios, project stakeholders must ensure local fire departments are prepared to respond safely to thermal runaway events.

Source: McKinnon, et al. "Four Firefighters Injured in Lithium-Ion Battery Energy Storage System Explosion – Arizona". UL Fire Safety Research Institute. July 28 2020.

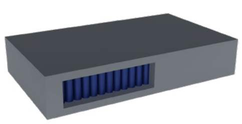
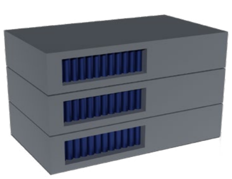
UL 9540A Test Sequence

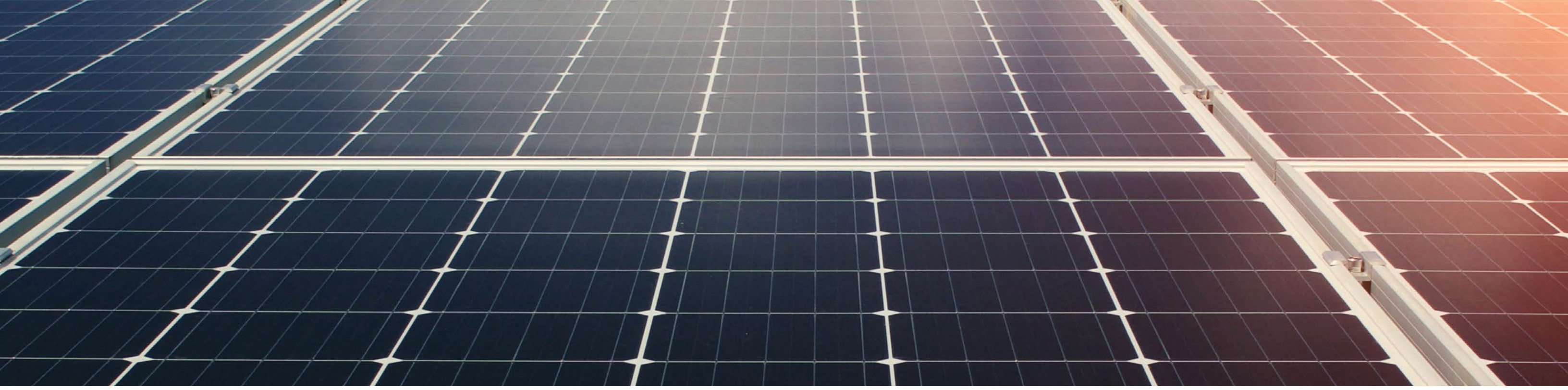
Over the last decade, risks associated with thermal runaway in ESS have become increasingly clear. The UL 9540A test standard was developed as a tool for assessing and mitigating these risks. Requiring UL 9540A has become the norm over the past five years as the ESS industry has matured.

Project developers can leverage the data that UL 9540A yields to alleviate the safety concerns of AHJs. While UL 9540A is not a pass/fail test, it does provide criteria which can be leveraged to improve the mitigation strategies and controls for the ancillary equipment responsible for keeping the system safe.

As shown in Figure 2 below, UL 9540A testing evaluates the capability of ESS to prevent and contain thermal runaway. Testing begins at the cell level, where thermal runaway is initiated in a single battery cell known as the target cell. Data such as temperature, gas composition, and burn properties are recorded. If thermal runaway cannot be induced or the cell vent gas is non-flammable, further testing is not required: thermal runaway can be contained at the cell level. If required criteria are not met, testing proceeds to the module, unit and installation levels to ensure that thermal runaway can be contained by the ESS. In some cases, product redesign and retesting are required.

Figure 2: Schematic of UL 9540A Test

Device under Test	Reported Information during Testing	Evaluation Criteria
Cell 	• Cell design • Thermal runaway methodology • Cell surface temperature when gas begins venting • Gas composition, lower flammability limit (LFL), burning velocity, maximum power	**Thermal runaway is contained if:** • Abuse factors (e.g.: mechancial and electrical stress; alternate heating source) do not induce thermal runaway • The cell vent gas is non-flammable in air **If the above criteria are not met, proceed to module-level testing.**
Module 	• Module design • Heat release rate • Gas generation and composition • External flaming and flying debris	**Thermal runaway is contained if:** • The module design prevents thermal runaway from propagating • The cell vent gas (based upon the cell level test) is non-flammable **If the above criteria are not met, proceed to unit-level testing.**
Unit 	• ESS design • Heat release rate • Gas generation and composition • Deflagration and flying debris hazards • Target (adjacent) ESS and wall surface temperature • Heat flux at target walls, ESS and means of egress • Re-ignition	**Thermal runaway is contained if:** • The target ESS temperature is less than the cell surface temperature at gas venting, and meets heat flux limits for means of egress • The temperature increase of target walls is less than 97° C (175° F) • No explosion hazards are exhibited by product • No flaming is observed beyond the outer dimensions of unit (indoor, wall mount) **If the above criteria are not met, proceed to installation-level testing.**
Installation 	• Fire protection equipment • Target ESS and wall surface temperature • Gas generation and composition • Deflagration and flying debris hazards • Heat flux at target walls • Re-ignition	**Thermal runaway is contained if:** • The target ESS temperature is less than the gas vent temperature measured in the cell-level test • The temperature increase of target walls is less than 97° C (175° F) • The flame indicator does not propagate flames beyond the width of the initiating BESS • No flaming is observed outside of the test room, and meets heat flux limits for means of egress



Using Data from Destructive Testing

Fire testing results provide important system design and installation insights. Understanding how thermal runaway is likely to propagate through cells, modules and racks informs site layouts, fire suppression techniques, equipment spacing, and overall system design and operations.

Large-scale fire test data also directly informs the design of fire protection systems such as suppression systems, deflagration vent panels and exhaust ventilation systems. Inclusion of these systems within an ESS container can mitigate the consequences of a propagating battery failure – or even prevent the event altogether. There are several different types of safety measures to consider.

Safety Measures

Release of Off-Gas by Exhaust Ventilation

Active exhaust systems prevent the accumulation of flammable off-gases during battery failures, thereby reducing the risk of explosion. The gas release rates measured during fire testing can be used to size exhaust systems.

Deflagration Vent Panels

Deflagration vent panels can provide pressure relief should an explosion occur in a container. The gas release rates measured during fire testing indicates whether these panels are required. Deflagration panels should be designed based on the methodology found in NFPA 68 - Standard on Explosion Protection by Deflagration Venting. Deflagration panels should also be located so as to direct the blast wave away from first responder accessways, nearby structures, or public pathways.

Water-Based Suppression Systems

Water is the most effective means of thermal cooling for lithium-ion battery failures. For maximum efficacy, water-based sprinkler systems should be designed using the heat flux, temperature, smoke and gas release measurements from large-scale fire testing. They should be installed within an enclosure to limit thermal spread between cells, modules and battery racks.

Gas-Phase Suppression Systems

Gas-phase suppression systems such as Novec 1230, FM-200, inert gas or aerosolized gas-based agents are often included in battery system enclosures to mitigate fire spread. While these systems are effective in adequately suppressing other types of fires in the battery space such as wiring insulation or electronics fires, and may help manage convective heat propagation, their effectiveness is limited for handling li-ion fires.

The Financial Impact of Fires

ESRG's independent analysis of thermal runaway events in South Korea reveals the high costs of these incidents. More than $44M USD in total losses resulted from 29 separate fire events that occurred between August 2017 and May 2020.

211 MWh of ESS were affected, bringing average losses to nearly $210,000 per MWh. The majority of events took place while systems were in standby mode after charging.

29 incidents in 3 years
$44M USD lost

Conclusion

At this stage of the energy storage market's growth, quality data is critical to timely permitting and efficient collaboration with AHJs, code officials, fire marshals and building departments. Most importantly, it is critical to public safety. By conducting UL 9540A testing early on in the planning process, developers gain important data that informs the design of safer energy storage systems, which are equipped with the appropriate fire suppression and thermal runaway mitigation controls. The results from UL 9540A can also be leveraged to support first responders as they develop emergency response plans.

Next Steps for Your Energy Storage Projects

Each energy storage development has a unique set of opportunities and challenges, as well as equipment providers and stakeholders. The key to a successful project, minimizing costs and timelines, is to proactively work with an experienced testing and safety partner to:

1. **Establish responsibilities**
   Create a responsibility matrix of all stakeholders (fire department, building officials, architects, fire protection engineers, manufacturers, financial and insurance) and determine the responsibilities for permitting.

2. **Review manufacturer's test results**
   Evaluate existing fire testing (i.e., cell and module level testing), if available, to confirm that it was done competently and to the latest revision of the UL 9540A test method.

3. **Conduct pre-certification testing**
   Perform pre-certification testing as part of the product development process at the unit/installation level as a means to eliminate surprises and reduce costs.

4. **Schedule UL 9540A testing in advance**
   Schedule and coordinate accredited fire testing in advance due to testing timelines, prototype/sample availability, and AHJ constraints.

5. **Leverage test results**
   Use the results in relation to the environment and context of the project (e.g. existing buildings, existing fire suppression, local or site-specific hazards).

6. **Demonstrate safety mindset**
   Demonstrate adherence to compliance requirements and safety-mindset to the community, including citizens, interest groups and firefighters.

Learn More

Contact PVEL and ESRG for more information.

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