UL Solutions

WHITE PAPER

Enhancing Energy Storage System Safety:

Evolving Large-Scale Fire Test Methods and Regulatory Demands

LET'S GO

Table of contents

Abstract 03

Introduction 04

NFPA 855 and key code requirements for ESS 05

Illustration of installation restrictions for lithium-ion BESS 06

How UL 9540, UL 9540A and NFPA 855 coordinate for ESS safety 07

UL 9540A testing levels 08

Regulatory demand and response for enhanced large-scale fire testing for nonresidential BESS 09

Key notes in the proposals for enhanced large-scale fire testing (LSFT) for nonresidential BESS 10

Conclusion 11

Energy storage safety support from UL Solutions 12

Abstract

This white paper underscores the safety codes and standards related to energy storage systems (ESS), including NFPA 855; ANSI/CAN/UL 9540, the Standard for Safety of Energy Storage Systems and Equipment; and ANSI/CAN/UL 9540A, the Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems. UL 9540A has been referred to as the large-scale fire test (LSFT) by NFPA 855 to evaluate the thermal runaway fire hazards of ESS. While LSFT methods in applicable safety standards continue to be refined through expert collaboration in the consensus process, other methodologies have been introduced. These other methods are not intended or recognized for use in satisfying the established safety code and safety standard requirements in North America. Because these other methods are different from and incompatible with the established safety requirements in the national standards for the United States (U.S.) and Canada, they introduce confusion into the ESS market and create risks for ESS manufacturers when misused to address essential safety requirements.

Introduction

The integration of energy storage systems (ESS) into the energy infrastructure is becoming increasingly prevalent, driven by various factors, including the escalating demand for renewable energy and the necessity for grid stability. Because of the overall growth in ESS deployment, the occurrence of fire incidents related to energy storage systems worldwide has also increased, with over 40 reported incidents since 2011, including six fires in 2024 alone [1]. The safety of ESS in the event of thermal runaway and subsequent fire propagation has emerged as a primary concern for manufacturers, installers and regulatory bodies across the globe.

Sampling of energy storage system fire incidents in 2024

Location	Event date	Description
Neermoor, Germany	April 27, 2024	One of several lithium-ion containers was observed to be smoking. The fire department consulted with the operator and opened the container, resulting in an explosion. Two firefighters were injured. The fire was extinguished in ten hours.
San Diego, CA, U.S.	May 15, 2024	The energy storage facility was involved in a fire, and water was pumped into the building's fire suppression system to extinguish it. A 600-foot safety barrier was maintained for over twenty two hours due to air monitors showing high levels of hydrogen. The fire was declared extinguished the next day but reignited several times until the fire department left the scene nearly seventeen days later.
Santa Ana, CA, U.S.	July 17, 2024	A Battery Energy Storage System BESS fire occurred in an industrial area, leading to a one-hour evacuation in the area due to smoke.
Escondido, CA, U.S.	Sept. 5, 2024	One of twenty four containers caught fire. Businesses adjacent to the substation or within approximately 0.25 mi were evacuated.
Singapore	Sept.10, 2024	An explosion and fire occurred in a lithium-ion BESS at a data center. Four water jets and the sprinkler system were used to contain the fire, and an unmanned firefighting robot was used to cool the batteries. The fire was declared to be under control after two days.

[1] BESS Failure Incident Database - EPRI Storage Wiki

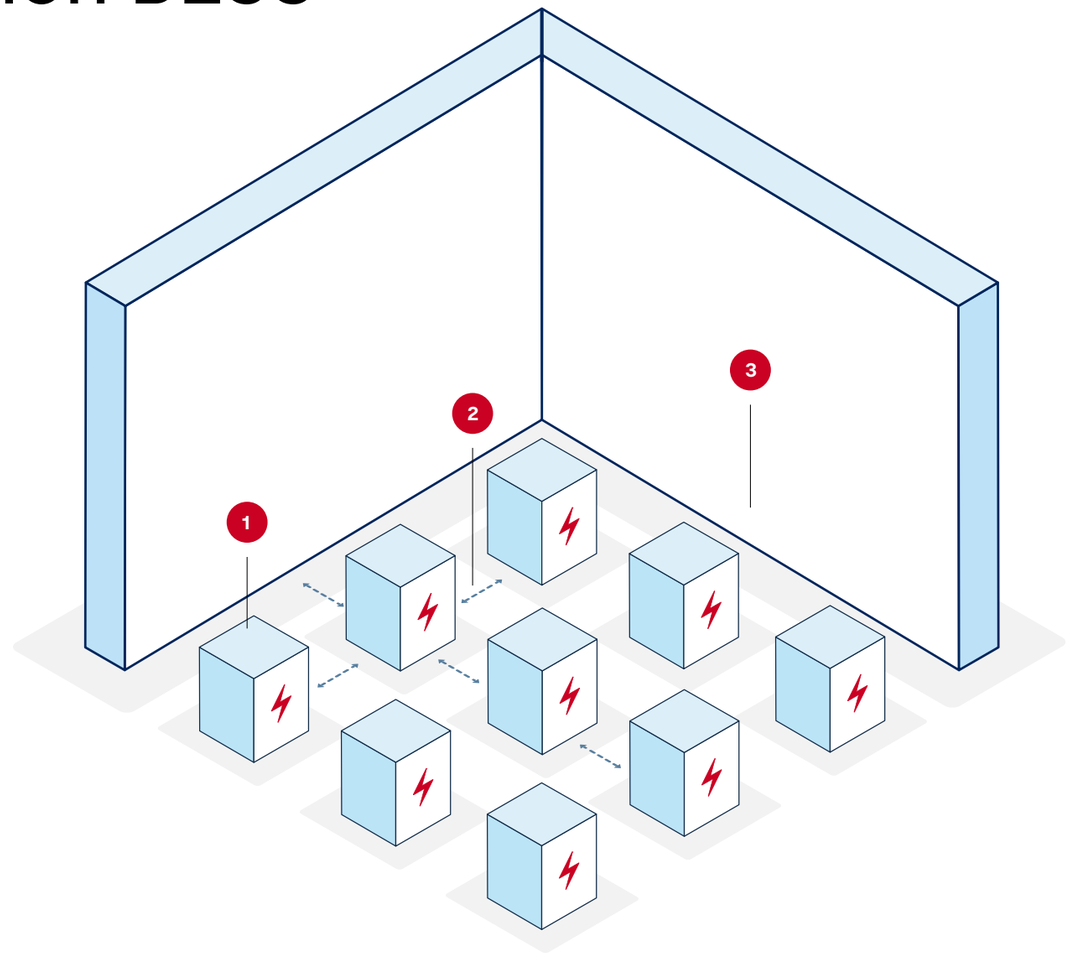
NFPA 855 and key code requirements for ESS

The Standard for the Installation of Stationary Energy Storage Systems, NFPA 855, issued by the National Fire Protection Association (NFPA), sets forth comprehensive requirements for energy storage systems, including installation, commissioning and maintenance. NFPA 855 mandates that ESS be listed to the safety requirements of UL 9540 (outlined below) and imposes numerous installation restrictions for battery energy storage systems (BESS) to mitigate fire hazards, including but not limited to the following:

- Maximum BESS size: 50 killowatt-hours (kWh)
- Minimum separation distance: 3 feet (ft)
- Maximum stored energy: 600 kWh (for lithium-ion BESS within a fire area)
- Fire barriers: 2-hour fire rating
- Minimum sprinkler density: 0.3 gallon per minute per square foot (gpm/ft2)
- Smoke and fire detection: mandatory
- Explosion control: explosion prevention per NFPA 69, deflagration protection per NFPA 68
- Minimum clearance to windows and doors for wall mounted: 5 ft
- Minimum clearance to egress: 10 ft

Illustration of installation restrictions for lithium-ion BESS

1. Each Unit Max. 50 kWh
2. Min. 3ft between units, from units to wall
3. Max. stored energy: 600kWh for Li-ion BESS



BESS that exceed installation limits in NFPA 855 require additional evaluation relative to fire hazards. For example, for nonresidential ESS configurations with individual units either spaced less than 3 feet apart or having a capacity larger than 50 kWh, large-scale fire testing in accordance with UL 9540A is required. This testing is essential to assess the safety of these ESS installations and supports manufacturers in obtaining installation approval from the relevant code authorities.

The Fire Code, NFPA 1 issued by National Fire Protection Association (NFPA), the International Fire Code (IFC) and International Residential Code (IRC), published by the International Code Council, also have requirements for safe ESS installations. The NFPA 1, IFC and IRC requirements for ESS are harmonized with NFPA 855, referencing both UL 9540 and UL 9540A for product safety and fire mitigation.

Note: The 2023 edition of NFPA 855 renames “large-scale fire testing” to “fire and explosion test,” while the test method according to UL 9540A remains unchanged. However, the 2024 edition of the IFC continues to use the term “large-scale fire testing” and cites UL 9540A for assessing fire hazards when those installation limits are exceeded.

How UL 9540, UL 9540A and NFPA 855 coordinate for ESS safety

UL 9540, the Standard for Energy Storage Systems and Equipment is the nationally adopted standard for the United States and Canada. This standard assesses overall product safety, covering electrical, mechanical, environmental and functional safety. Furthermore, the standard addresses risks associated with component interactions and compatibility, the operation and maintenance of ESS, as well as the integration of ESS with electrical grids. As previously stated, safety codes require ESS to comply with the requirements of UL 9540. For ESS installations exceeding NFPA 855 limits, UL 9540 also mandates large-scale fire testing in accordance with UL 9540A.

UL 9540A, the Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, was developed to establish standard test methodologies for assessing the hazards associated with fire propagation associated with thermal runaway events in the batteries of ESS. UL 9540A is the American and Canadian National Standard for this important safety issue, and testing to these national standard requirements is an important element of due diligence. UL 9540A provides a methodology to test the system's safety-related behavior when the design or installation conditions of an ESS exceed the limits set by NFPA 855, NFPA 1, IFC or IRC.

As bi-national U.S. and Canadian consensus standards, UL 9540 and UL 9540A are the result of a balanced and open collaborative process involving industry, professional organizations, government agencies, manufacturers and other expert stakeholders.

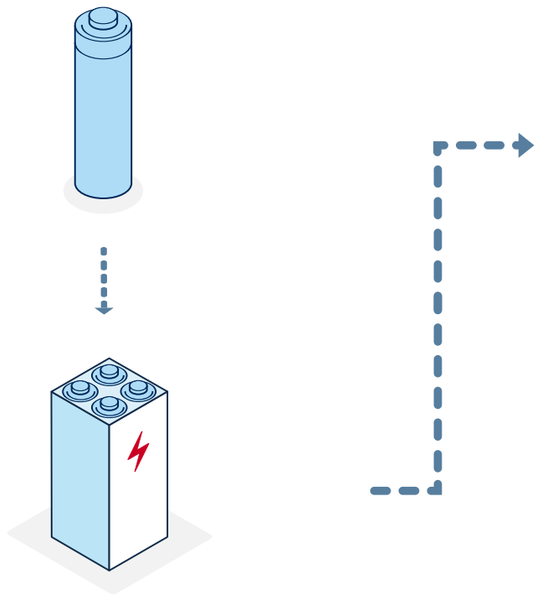
In the ESS sector, there is a coordinated synergy between the UL 9540, UL 9540A and the NFPA 855 standards and the applicable codes. UL 9540 provides product safety criteria for ESS, UL 9540A provides methodologies for testing thermal runaway and fire spread in energy storage systems, while NFPA 855 addresses the installation and similar use requirements. Though these standards focus on different aspects, they complement each other, collectively enhancing the safety of ESS. The applicable codes address electrical, fire and other safety requirements that are enforced by regulatory authorities in their jurisdiction and rely on compliance with the standards to demonstrate safety of the ESS installations.

UL 9540A testing levels

UL 9540A was first published in November 2017 and was updated to a consensus standard in its fourth edition in 2019. It encompasses four levels of testing. For lithium-ion battery energy storage systems, the first three levels of testing, from cell level to unit level, are generally required. If flames or other noncompliance indicators are observed at the unit-level test, the installation-level test is needed.

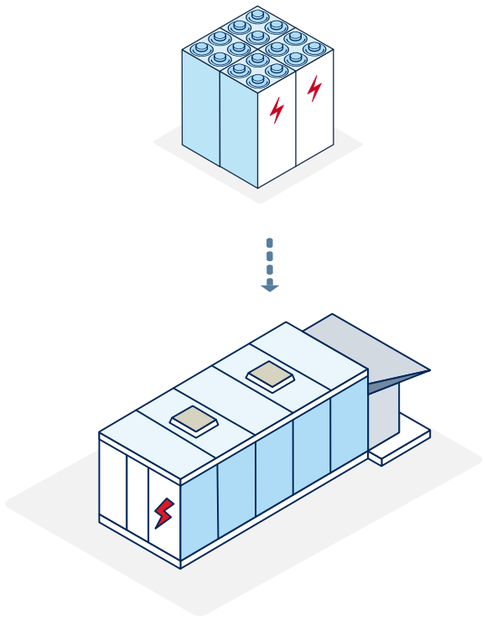
UL 9540A has achieved international adoption, with ESS installation regulations in Singapore, Malaysia and the Australian state of Victoria referencing UL 9540A to permit specific installation scenarios.

Cell-level test
Cell-level testing evaluates the thermal runaway characteristics of the cell as well as the composition and flammability of the gases.



Module-level test
Module-level testing evaluates the tendency of cell thermal runaway propagation, the heat and gas release rate of the module, and the potential danger of ignition or deflagration.

Unit-level test
Unit-level testing evaluates the likelihood of fire spread between modules, the unit's heat and gas release rates, and the potential for deflagration or re-ignition.



Installation-level test
Installation-level mainly evaluates the effectiveness of the fire protection system, as well as the heat and gas release rate of the system and the danger of deflagration or re-ignition.

Regulatory demand and response for enhanced large-scale fire testing for nonresidential BESS

With the increasing number of ESS safety incidents, global concern for ESS safety has heightened, especially for large-scale BESS. Some regulatory bodies have called for enhanced large-scale fire testing of nonresidential BESS, seeking to evaluate how fire spreads within and between units following a developed fire condition within the initiating unit. This enhanced testing is to provide robust data to support firefighting strategies and rescue operations for large-scale BESS incidents.

In response to this need, the Technical Committee responsible for UL 9540A has established a dedicated task group focused on large-scale fire testing (LSFT) for ESS. This task group has worked in tandem with the NFPA Technical Committee, conducting multiple discussions and formulating a preliminary testing procedure. Their unified objective is to create clear guidance and a consensus-based standard test method for LSFT that could be easily used by manufacturers for testing and by code authorities for oversight. The consensus testing methodology is expected to be integrated into the UL 9540A Standard, and the guidance on the test objectives is expected to be included in the Annex of the 2026 edition of NFPA 855.

Meanwhile, some organizations have introduced their own large-scale fire testing procedures for BESS and are promoting their testing services. It is important to note that UL 9540A remains the only consensus standard explicitly cited in NFPA 855 for large-scale fire testing and the only national standard in the U.S. and Canada for fire safety testing methods for BESS. Testing to standards that have not been adopted on the national level, have not been developed based on the consensus of all interested parties and do not aim to ensure safety may lead to rejection of ESS installations by relevant regulatory bodies and subsequent issues with failure to comply with identified national safety standards.

It is important to note that UL 9540A remains the only consensus standard explicitly cited in NFPA 855 for large-scale fire testing and the only national standard in the U.S. and Canada for fire safety testing methods for BESS.

Key notes in the proposals for enhanced large-scale fire test (LSFT) for nonresidential BESS

The LSFT assesses the thermal risks from fires within BESS and the potential for fire to spread to nearby units or occupancy areas. It provides quantitative data on thermal exposure but is not designed to evaluate flammable gas accumulation prevention, deflagration mitigation or the reliability of safety systems. The test excludes residential BESS less than 20 kWh in capacity.

Before performing the LSFT, cell-level testing should be conducted according to UL 9540A to characterize cell-level thermal runaway performance and gas flammability.

The test setup should reflect the final installed configuration of BESS, ancillary equipment and targets, representing any immediate surrounding enclosure or buildings. Fire protection systems installed in accordance with applicable codes and standards may be installed and active in all enclosures in the test. Active thermal runaway mitigation technologies can be incorporated in all adjacent enclosures but will be deactivated in the enclosure or rack of origin. Ventilation paths in the enclosure should be opened if they are anticipated to be opened due to a deflagration in the enclosure of origin.

A burner or heater plus ignitor is to be used as one of the ignition methods, to cause overheating of the BESS unit of origin, resulting in a developed fire condition. During the test, data on battery reaction, fire spread, and the temperatures of the BESS and adjacent targets will be captured.

The compliance criteria for LSFT demonstrate the critical fire safety concerns regarding the spread of fire to other BESS and surrounding areas.

- The fire shall not propagate to the adjacent BESS during the testing.
- The surface temperature of modules within the adjacent BESS units shall not exceed the temperature at which thermally initiated cell venting occurs, according to UL 9540A cell-level testing.
- Ignition of combustible materials on or in any adjacent enclosure shall not occur during testing.
- Venting or thermal runaway of any cells in adjacent BESS shall not occur.

This comprehensive fire test, developed through a consensus process with expert involvement, demonstrates that the BESS design and spacings will not contribute to a cascading, hazardous fire event.

Conclusion

As the deployment of ESS accelerates globally, increasing their safety and reliability becomes more critical. The establishment of safety standards such as NFPA 855, UL 9540 and UL 9540A reflects the industry's collective commitment to safer ESS design and operation. Manufacturers also obtain significant benefits from demonstrating due diligence through conformance to published national standards in the U.S. and Canada rather than other documents that do not fully address the requirements of safety codes and regulations.

Through our expertise in safety research, testing and certification of ESS, UL Solutions collaborates with the NFPA on the consensus standard for LSFT, helping to minimize risks, protect consumer interests and advance the safe and orderly growth of the ESS market. The updates to and international adoption of UL 9540A, along with the response to calls for enhanced large-scale fire testing, further reinforce this commitment. Through ongoing collaboration, we can collectively increase the resilience of our energy infrastructure and the safety of communities worldwide.

Energy storage safety support from UL Solutions

As a pioneer in the field of battery and energy storage safety, UL Solutions has extensive experience in safety research, testing and certification of batteries and energy storage systems. We also work closely with the code authority community, the NFPA, the fire service, and other experts dedicated to collaboration for safer and more responsible deployment of ESS technology. UL Solutions leverages our extensive industry connections and experience to help customers understand and appropriately navigate the latest and most comprehensive ESS codes and regulatory requirements.

We provide the following services to global battery and energy storage manufacturers:

- UL 1973 energy storage battery testing and certification
- UL 9540 energy storage system safety testing and certification
- UL 9540A large-scale fire testing reports
- Customized large-scale fire testing reports
- NFPA 855, NFPA 68, NFPA 69 compliance assessments

UL Solutions has extensive testing experience in LSFT, having assisted numerous customers globally in designing test methods and conducting experiments. We serve our customers with a scientifically rigorous approach, applying our deep expertise in ESS safety to help ESS manufacturers complete a comprehensive safety assessment before deployment, boost customers' confidence that hazards have been successfully addressed, and provide thorough reports that promote ready acceptance by regulatory authorities across geographies. Our objective is to minimize the safety risks associated with energy storage products, safeguard the interests of energy storage customers and foster safer systematic growth of the ESS market.

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