UPS vs ESS

What is the current state of North American codes and standards for these two battery applications?

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Executive summary

Uninterruptible power supply (UPS) technologies have been used in various applications for many years to support continued operation of key loads during interruptions of power from the grid. These systems have been used in many different locations to provide additional immunity from grid interruptions interfering with the operation of defined loads. UPS systems are often used to protect computers, computer facilities and telecommunication equipment.

With the recent evolution of new energy technologies, energy storage systems (ESS) have proliferated rapidly. ESS, particularly those using battery technologies, are typically supplied by renewable sources such as solar or wind power and enable the storage of energy produced by these sources for use at different times. The timing associated with the use of the stored energy might be driven by when the sources are limited in producing energy (e.g. diurnal limits for solar power), by energy consumer decisions (e.g., grid power premium pricing), or other factors.

Safety standards have progressed for both UPS and ESS. The current US ANSI standard for UPS is UL 1778, the Standard for Uninterruptible Power Systems. and CSA-C22.2 No. 107.3 for Canada. UL 9540, the Standard for Energy Storage Systems and Equipment, is the American and Canadian national standard for ESS. These standards and others have evolved in recent years, especially with the increased use of lithium-ion batteries.

While both the mature UPS products and the rapidly evolving ESS produced have some commonality in technical solutions, operations and installation, there are important differences. This paper will review the critical differentiations, outline the applicable product safety requirements associated with each and summarize how codes are evolving in addressing both types of installations.

Introducing uninterruptible power supply systems

A UPS system is an electrical system designed to provide instantaneous temporary alternating current-based power for critical loads in the event of electric grid failure or other mains power source failure modes. The UPS is sized to provide an instantaneous continuation of a predetermined amount of power for a specific duration. This allows a secondary power source, e.g., a generator, to come online and continue with power backup. The UPS may safely shut down non-essential loads while continuing to provide power to more important equipment loads. UPS systems have been providing this critical support for various applications for many years. A UPS will utilize stored energy from an integrated energy source. This is typically battery bank, supercapacitor or the mechanical movement of a flywheel as an energy source.

A typical UPS using a battery bank for its supply consists of the following main components:

- Rectifier/charger – This UPS section takes the AC mains supply, rectifies it and produces a DC voltage used to charge the batteries.
- Inverter – In the event of a mains supply failure, the inverter will convert the DC power stored in the batteries into clean AC power output suitable for the supported equipment.
- Transfer switch – An automatic and instantaneous switching device that transfers power from various sources, e.g., mains, UPS inverter and generator, to a critical load.
- Battery bank – Stores the energy needed for the UPS to perform its intended function.

Current standards for UPS systems

The current U.S. ANSI standard for UPS is UL 1778/C22.2 No. 107.3, the Standard for Uninterruptible Power Systems, which define a UPS as “a combination of converters, switches, and energy storage devices (such as batteries) constituting a power system for maintaining continuity of power to a load in case of input power failure.” Under development are new editions of IEC 62040-1 and IEC 62477-1. UL/CSA 62040-1 (using UL/CSA 62477-1 as a reference Standard) will be harmonized with these standards.

Introducing energy storage systems (ESS)

ESSs are gaining traction as the answer to a number of challenges facing availability and reliability in today's energy market. ESS, particularly those using battery technologies, help mitigate the variable availability of renewable sources such as solar or wind power. ESS are a source of reliable power during peak usage times and can assist with load management, power fluctuations and other grid-related functions. ESS are used for utility, commercial, industrial and residential applications.

Current standards for ESS

UL 9540, the Standard for Energy Storage Systems and Equipment, is the American and Canadian national standard for ESS. First published in 2016, UL 9540 includes multiple technologies for ESS including battery energy storage systems (BESS). UL 9540 also covers other storage technologies: mechanical ESS, e.g., flywheel storage paired with a generator, chemical ESS, e.g., hydrogen storage paired with a fuel cell system, and thermal ESS, e.g., latent heat storage paired with a generator. UL 9540 is currently in its second edition and is undergoing further updates through the UL Standards consensus process in 2021-2022.

UL 9540 defines an energy storage system as "Equipment that receives energy and then provides a means to store that energy in some form for later use in order to supply electrical energy when needed." The second edition of UL 9540 further requires that a BESS be subjected to UL 9540A, the Standard Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems, if required to meet exceptions in the codes.

Comparing ESS with UPS

An ESS is similar in construction to a UPS but differs in its usage. Like UPS, ESS includes an energy storage mechanism such as batteries, power conversion equipment, e.g., inverters, and various other electronics and controls. Unlike the UPS, however, an ESS may operate in parallel with the grid, which results in greater cycling of the system than a UPS would ever experience. An ESS can collaborate interactively with the grid or in a standalone mode, or both, depending upon the type of power conversion system employed. An ESS may even provide a UPS functionality, although that is not the primary function of an ESS.

Increasing renewable energy usage

The increased use of renewable energy has led to an increase in the use of energy storage to support that industry, in addition to the support of older forms of power generation, especially during peak usage hours. Storing energy often proves significantly less expensive than increasing power capacity during peak usage hours when demand is highest and electricity pricing might also be highest. Large scale ESS also provide other services that support the stability of the electrical grid. Like UPS, ESS can come in a variety of sizes from a small residential system that is less than 20 kWh of energy to utility applications using multi-megawatt energy container systems with multiple battery racks within the container.

Using lead-acid or nickel-cadmium batteries for UPS

The typical battery chemistry used for UPS has long been lead-acid or nickel-cadmium. Both are noncomplicated, robust systems that have a proven track record of safety over the years. UL 1778, the Standard for Uninterruptible Power Systems, (through its embedded reference to UL 60950-1) refers to UL 1973, the Standard for Batteries for Use in Stationary and Motive Auxiliary Power Applications, for technologies other than lead-acid or nickel-cadmium.

In some installations, rooms of battery racks used for UPS type applications were not part of the UL 1778 certification.

Resolving/reducing chemical battery incidents

Large UPS systems often are supported by racks of lead-acid batteries in a separate battery room. The fire concerns of these topologies address fire safety through the control of quantities of electrolyte, which have been essentially constructed in size to be installed in one room) and ventilation (to cover the potential off-gassing of hydrogen from these aqueous electrolyte batteries).

Increasing use of lithium-ion in ESS

Unlike a UPS, a BESS has from the onset typically used technologies such as lithium-ion over older technologies such as lead-acid due to the greater cycling performance of the lithium-ion batteries as well as their higher energy density, which allows more energy in a smaller physical footprint. Lithium-ion batteries also have much lower maintenance requirements than traditional battery technologies.

The price of lithium-ion batteries, which discouraged their use in the past, has decreased due to their increased usage in, and production for the electric vehicle industry. Lithium-ion batteries are also increasingly being used for UPS applications based on these advancements. With lithium-ion UPS, some manufacturers in a popular trend offer their UPS for applications beyond UPS services due to the increased energy available. This can include more cycling capability that is widely provided by ESS. Although a much shorter history of their use for UPS applications, the lithium-ion UPS systems possess a good record of safety thus far. This is also true for their use in ESS. However, there have been some incidents with this chemistry and there are concerns regarding its safety in both the ESS and UPS applications.

ESS with lithium-ion adds complexity

An issue with lithium-ion safety that is unique from that of the traditional lead-acid technologies is the complexity of a lithium-ion battery system. Unlike the type of control systems used to charge and discharge lead-acid batteries, a lithium-ion battery system requires a programmable electronic battery management system (BMS) that carefully monitors the voltages, temperatures and current of the lithium-ion batteries to maintain them in a safe state. For racks of battery modules, the BMS is typically a separate part installed on the rack, monitoring and controlling multiple modules in the rack. If the voltage and temperature of the lithium-ion cells are not maintained within the manufacturer's specifications for safe operation, risks of a chance that the cells can go into thermal runaway and propagate to other cells within the battery modules that may then cascade to other modules in the rack or even other racks in the system in an uncontrolled fashion.

Large multirack container BESS typically have an energy storage management system (ESMS) that intakes the information from the BMSs and other devices in the BESS and coordinates the activities between the various controls. The BESS also must work in coordination with the power conversion system (PCS) that it is connected, and for it to safely operate in its intended application. All these various safety controls add to the complexity of these systems and the potential for something to go wrong if not appropriately designed and evaluated as a system for safety.

Rising concern about lithium-ion batteries

The lithium-ion and other emerging battery technologies have been a concern for regulators and other critical stakeholders as there are many unknowns regarding their overall fire behavior and safety. Some of the concerns surrounding the use of lithium-ion systems have been due, perhaps unfairly, to several nonstationary incidents that have been well-publicized. These include incidents involving consumer electronics and more recently, problems with hoverboards and e-bikes; even though these applications may not be using the same type of lithium-ion technology as the stationary applications.

However, there was a serious incident in 2019 involving an ESS used for a utility application in Arizona that resulted in the severe injury of several first responders. All these various incidents involving lithium-ion batteries, whether they are directly related to stationary battery storage or not, have gained the attention of regulators and various stakeholders such as insurance agencies. To ensure that this growing field was not hindered by avoidable safety incidents, there came a need for a significant effort to develop suitable codes and standards for ESS. To encourage the development of appropriate safety codes and standards for ESS, the U.S. Department of Energy (DOE) in 2015 initiated the first of what would become a yearly forum on the safety and reliability of ESS.

New ESS codes and standards emerge

The first DOE ESS forum led to a great deal of work with codes and standards to address ESS. Most notable was the development of Article 706 in the NEC and the development of NFPA 855, the standard for the Installation of Stationary Energy Storage Systems, which directly influenced the criteria for stationary battery systems in the ICC IFC and NFPA 1. After that first DPE meeting, UL 9540 went on to be published as a consensus standard in 2016. At the writing of this paper, UL 9540 is in its second edition and is undergoing further updates through the UL Standards consensus process in 2021-2022. Also, there have been updates for the 2023 editions of the NEC and NFPA 855.

Increasing standards confusion

Although the goal of all this code and standard development activity was to adequately address the safety of these systems, these developments, unfortunately, resulted in some confusion for the industry. Comments received for the 2023 edition of the NEC include many that point to general confusion regarding when Article 706 for ESS applied or when Article 480 for storage batteries applied. Some users of the NEC believed that both Article 480 and Article 706 applied together. This general confusion regarding the application of which article applies to the system has been the case since the first publication of Article 706 in the 2017 edition of the NEC.

NFPA 855

Perhaps the most critical document impacting the installation of BESS and UPS was the 2020 edition of NFPA 855, Standard for Installation of Stationary Energy Storage Systems. NFPA 855 defines energy storage as "one or more devices assembled together capable of storing energy in order to supply electrical energy at a future time to the local power loads, to the utility grid, or for grid support." This definition would include both UPS and ESS-type applications. In addition, NFPA 855 and the fire codes require that the ESS be evaluated and receive certification to UL 9540. This has created some confusion for the industry as UL 1778 has been the traditional product safety standard for UPS. Listing is an important step to establish the system has been independently evaluated for conformity to the applicable safety requirements and to support safe installation. However, the specific reference to only UL 9540 has created some confusion for the industry as UL 1778 has been the traditional product safety standard for UPS.

Some limited exceptions exist on the utility and telecom application of NFPA 855, which utilizes lead-acid or nickel-cadmium batteries. For the 2023 edition of NFPA 855, an exception for lead-acid and nickel-cadmium batteries at or below 600 volts of direct current (VDC) and intended only for stationary standby applications if they have UL Listing to UL 1973. NFPA 855 defines a stationary standby application as "An energy storage system utilizing a battery that is intended to remain on continuous float charge or in a high state of charge to support an event necessitating a discharge." A UPS falls into this definition. Lithium-ion battery systems, whether UPS or ESS, have not received such an exception.

One of the primary goals of NFPA 855 (and the fire codes) was to address the concern for the potential fire and explosion hazards associated with a UPS or BESS. For example, to control these hazards, very stringent limits for energy capacity and separation distances are placed on these systems. Some of these limitations are noted in Table 1 below. Exceptions to many of these limitations based upon the results of a large-scale fire test (LSFT) of the system in accordance with UL 9540A are present.

UL 9540A Standard for ESS

UL 9540A is a comprehensive tiered method starting at the cell level through the installation level that first determines if a battery technology can be driven into thermal runaway. If this condition is possible, what are the fire and explosion hazard characteristics of the system? Testing provides data to determine if the installation has sufficient protection to address these hazards. This test method provides essential information regarding the behavior of these stationary battery systems when a fault occurs and how to safely integrate them into the built environment. Testing can evaluate the type of fire suppression, and if necessary, the

type of explosion protection required for the installation. The gas data collected during the testing can be used for a deflagration hazard study as required by NFPA 855. All the critical data generated during the UL 9540A testing is put into a report for the authority having jurisdiction (AHJ) to review and approve the installation. Unless a BESS or UPS installation is limited in accordance with the limitations, such as those noted in Table 1 below, there must be a large-scale fire test, per UL 9540A, conducted with results that can evaluate the safety of the intended installation.

Table 1 — Limitations on ESS/UPS in NFPA 855/NFPA 1 and ICC IFC

Parameter	Location of system	Limit	Exception
Maximum size	All locations	50 kWh	LSFT[a]
	Residential	20 kWh	[b]
Separation from other ESS	Indoor and Outdoor	3 ft	LSFT
Maximum stored energy	Indoor, Outdoor near exposures	600 kWh	LSFT
	Residential	40-80 kWh	[b]
Fire Suppression	All non-residential locations	0.3 gpm/ft^2	LSFT
Explosion control	Indoor and Outdoor – nonresidential	NFPA 68, NFPA 69	LSFT

[a] – LSFT refers to large-scale fire testing. UL 9540A is provided as an approved test method.
[b] – If a residential system is to increase the size or maximum stored energy in an area, then all of the criteria that apply to nonresidential, e.g., fire suppression, explosion control, apply to these residential systems including LSFT.

These requirements resulted in UPS systems being subjected to criteria for listing that were not required in the past. It has also been challenging for UPS systems to use more traditional technologies such as lead-acid batteries that were not subjected to the limitations now being imposed by including UPS in ESS standards and code criteria. Some limited exceptions for lead-acid and nickel-cadmium technologies for low voltage telecom applications and utility applications are noted above. With the 2023 edition of NFPA 855, there is also some relief for lead-acid and nickel-cadmium that have UL Listing to UL 1973. However, BESS using these traditional technologies and UPS systems and BESS using lithium-ion technologies will need to meet these ESS limitations or be subjected to large-scale fire testing.

Unwinding the confusion

Since the initial publications of these various codes and standards to address ESS safety, new work is underway to remove some of this confusion and to include code/standard language that better addresses the various applications and technologies that utilize batteries for energy storage. Although the goal of all this code and standard development activity was to adequately address the safety of these systems across the suite of codes, these developments did result in some confusion for the industry. That has driven the continued considerations of driving clarity, leveraging insights from field experience, and addressing innovations with new or revised code requirements. 2023 editions of both the NEC and NFPA 855 address enhanced requirements for UPS and ESS installations. The 2023 edition of the NEC clarifies installations that fall under the scope of Article 480 and those that fall under the scope of Article 706. Proposals received in the development process sought to resolve confusion regarding when Article 706 for energy storage systems applied or when Article 480 for storage batteries applied. Some users of the NEC believed that both Article 480 and Article 706 applied together to particular installations. Changes to the 2023 NEC will resolve this issue.

NEC Article 480

Article 480 is retitled "Stationary Standby Batteries" with a definition that indicates "A battery that spends the majority of the time on continuous float charge or in a high state of charge, in readiness for a discharge event." It includes the following informational note: "Uninterruptible Power Supply (UPS) batteries are an example that falls under this definition." The scope for Article 706 scope will indicate, "This article applies to all energy storage systems (ESS) having a capacity greater than 3.6 MJ (1 kWh) that may be stand-alone or interactive with other electric power production sources. These systems are primarily intended to store and provide energy during normal operating conditions." The scope then includes the following informational note: "See Article 480 for installations that meet the definition of stationary standby batteries."

UL 1973 Annex H

The changes to the 2023 edition of NFPA 855 will also bring additional clarity. For the 2023 edition of NFPA 855, there is also an exception for lead acid and nickel cadmium batteries at or below 600 Vdc and intended only for stationary standby applications if they have been Listed to UL 1973. NFPA 855 defines a stationary standby application as "An energy storage system utilizing a battery that is intended to remain on continuous float charge or in a high state of charge to support an event necessitating a discharge." A UPS falls into this definition. There are no such exceptions however for lithium ion battery systems whether they are for a UPS or an ESS. This change to the 2023 edition of NFPA 855 clarifies that these specific lead-acid and nickel-cadmium batteries

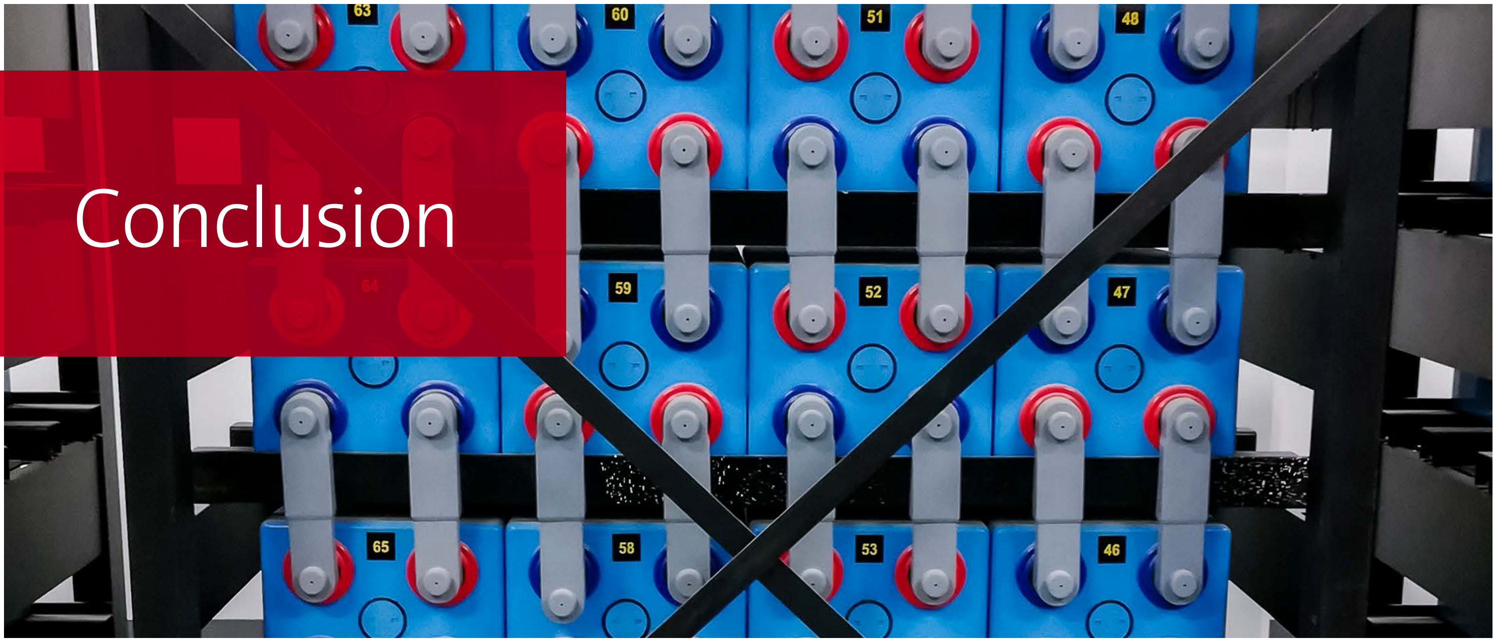
(600 V or less) that have been listed to UL 1973 and are intended for use in stationary standby applications such as UPS do not need to also be listed to UL 9540. The Listing option for lead-acid and nickel-cadmium batteries came about as an effort to better address the concerns for safety of the older technologies in these ESS codes. This effort started with the need to revise UL 1973 to better address lead-acid and nickel-cadmium batteries. As part of the effort to address the gaps in UL 1973 for lead-acid and nickel-cadmium batteries, UL and industry stakeholders from the IEEE ESSB committee worked together on developing criteria for listing these batteries, so that they could be safely installed in the field whether for UPS or ESS applications. This criterion has been published as a new Annex H in the third edition of UL 1973 published in February 2022. This Annex H program represents a comprehensive evaluation at the cell and multicell battery (monobloc) level for these technologies to establish their safety to be installed in the field based on comprehensive installation, maintenance and operating instructions.

This approach best fits those batteries that are not typically evaluated as a system and allows them to be installed safely in the field. The Annex H program also represents a step forward in increasing the safety evaluation of batteries that have been traditionally installed without the benefit of this type of comprehensive evaluation. In the past, there were often rooms filled with these batteries that had no third-party safety certification. They were often not part of the UL 1778 certification of the UPS system.

The UL 1973 Annex H test program is noted in Table 2 below. The overcharge thermal runaway test has been proposed for inclusion in UL 9540A and is currently published as a Certification Requirement Decision (CRD) to be applied prior to its inclusion in the UL 9540A Standard. The goal of the industry is to also get UL 1973 Annex H criteria referenced in UL 1778 for UPS to bridge the current gap in safety criteria for these technologies.

Table 2 — UL 1973 Appendix H Tests for lead-acid cells and batteries

Test	Cells or Multi-cell Batteries	Systems
Overcharge	X	
Short circuit	X	
Over-discharge	X	
Temperature	X	X
Dielectric voltage withstand	X	X
Continuity		X
Static force (system enclosure)		X
Impact (system enclosure)		X
Drop impact	X	
Mold stress (system enclosure)		X
Strength of the support structure (system rack)		X
Salt fog	X	
Overcharge thermal runaway	X	



Conclusion

These changes represent a positive development for differentiating between the safe installation requirements for UPS versus those of ESS. Further work needed includes updating NEC Article 480 to better address installment requirements for technologies beyond lead-acid and nickel-cadmium, which were the original focus of Article 480. In addition, further work is required to update criteria in NFPA 855 and the fire codes might increase clarity, especially regarding all the various technologies being used for stationary applications regardless of whether they are UPS or ESS.

For ESS, there is work currently underway to update UL 9540 to address various concerns including updates to tests and the criteria for an external warning communication system for large grid-scale container ESS. To improve the test method for several types of installations including for residential and large grid-scale container systems as well as various technologies including flow batteries, high-temperature sodium and other molten salt batteries, lead-acid and nickel-cadmium battery systems here are proposals for UL 9540A. The UPS harmonization efforts for UL/CSA 62040-1 noted above should reference the UL 1973 Annex H criteria to fill the gap currently in existence with regard to the racks of batteries that are being used in UPS applications but were not part of the initial UL 1778 investigation. The authors hope the ongoing changes will result in improved safety for the industry regardless of whether the application is a traditional UPS or an ESS. As we see energy storage solutions proliferate in important and rapid manners maintaining a strong foundation of safety will be critical for unlocking safe innovation and meeting society's needs.

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