NEW ENERGY IN THE BATTERY INFRASTRUCTURE

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Paper Overview

Over the past several years, there has been a significant effort to address energy storage system (ESS) safety especially those systems that utilize batteries as their source of energy. New technologies that do not have a long history of use in the built infrastructure are being utilized. Based on this, there is concern from regulators, fire marshals, electrical inspectors, building owners and other industry stakeholders with the safety of these systems and how to best integrate them into facilities. Development of product safety standards and product installation standards, and updating of building codes to address these concerns have been ongoing. This work as culminated in the publication of American and Canadian national standard UL 9540 to evaluate the safety of energy storage systems involving a global standard technical panel to come to consensus on the requirements of the standard as well as the ongoing development of national code for energy storage system installation known as National Fire Protection Association (NFPA) 855. There is also a USA national electrical code that in 2017 introduced a new content called Article 706 and revisions to existing content in Article 480 as well as new updates happening both at the USA national and international fire codes known as NFPA 1 and the International Fire Code (IFC), which collectively have had an impact on the ESS industry. Specific to the codes, newer updates have started to call out the requirement of large scale fire testing in order to demonstrate that a single cell failure in a product does not result in catastrophic failure of the system. In response to the recent updates, UL published a new test method with support of manufacturers and fire services such as Fire Department of New York City (FDNY) at the end of 2017 called UL 9540A. This method is to address how to conduct a proper fire propagation study of a Battery or ESS system. Further to that, UL has been looking beyond the first use case of a battery system, and will be publishing this year UL 1974, an American and Canadian national standard to address the process for determining a facility’s ability to take used batteries and repurpose them for new applications such as energy storage. All of this work will have a direct impact on the industry, and it is important to know what to expect when trying to site these systems.

This paper (and coinciding presentation) will provide an overview of how an ESS product is to be evaluated, tested, and certified for safety using the world’s first and leading safety standard for ESS UL 9540 as well as provide how to evaluate a complete system of energy storage including the power conditioning system. It will also present an overview of various USA and international code developments impacting the industry, including limitations on size and siting and exceptions allowed based upon large scale fire testing. An overview of the UL 9540A large scale fire test method developed by UL with input from industry and the fire safety community, and the new UL 1974 repurposing standard as there is interest in utilizing repurposed electric vehicle batteries in stationary applications and concern regarding the safety of the used batteries will also be provided.
Introduction

Energy Storage Systems and Equipment is essentially a device that can store energy in some form such as battery energy storage and provides usable electrical energy as a standalone source to a local grid or in parallel with an electric utility grid or both. The energy storage system may have capability to provide backup power as a UPS when utility power goes out, but it is not used exclusively for that purpose.

Energy storage systems are being utilized for grid support, transmission support, support for renewable energy sources and arbitrage and other cost savings measures as well as for power quality and reliability. Energy storage systems are being installed in front of the utility meter, but also behind the meter in areas where they are closer to the user such as in and around commercial and residential buildings. They are also using a number of newer technologies of batteries, which concerns the authorities having jurisdiction (AHJs) such as fire marshals and building inspectors with regard to their safety. To address the concern of various stakeholders, new safety standards, new installation standards and updates to current model codes have developed over the past few years to address energy storage system safety.

US Safety Standards Impacting Energy Storage

Battery energy storage systems are essentially an assembly of major components such as the battery system with its battery management system (BMS), the power conditioning system, an overall system control, and HVAC and other balance of plant components that are required for the energy storage system to operate as intended (See Figure 1). Each of these major components may have its own safety standards addressing the safety of that individual component. The energy storage system standard, UL 9540, addresses the safety of the overall assembly making reference of these major component standards. UL 9540 references UL 1973, a well-known and established stationary battery safety standard used by all leading stationary battery system makers and other critical component standards meeting their requirements and then includes testing and construction criteria to address the safety of the overall device. See Figure 2 on page 4 for component battery standards used to evaluate batteries for these standards.

Figure 1 – Example Lithium ion Battery Energy Storage System Installed in Sterling, MA
Energy Storage System Safety Standard - UL 9540 Overview

American and Canadian national standard UL 9540, Energy Storage System and Equipment, is a bi-national safety standard for the USA and Canada, whose scope covers energy storage systems, and includes electrochemical, chemical mechanical and thermal type storage technologies. It was published on November 21, 2016 and includes construction, both type and routine production test criteria with which to evaluate the safety of an energy storage system. A critical aspect of UL 9540 approach is the safety analysis, which can be in the form of a Failure Mode and Effect Analysis (FMEA) or similar type of safety analysis that considers potential risks associated with the system design, the potential for risk to occur and its severity, and the protections used to mitigate the risk. This analysis should guide the level and type of safety controls that need to be employed in the design. Identified critical components are required to be evaluated for reliability.

Major components that make up ESS are required to comply with their applicable safety standard. For power conditioning system, this would be UL 1741, Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources and for battery systems, and UL 1973, Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications.

UL 9540 is referenced in the model codes such as NFPA 70, National Electrical Code (NEC), and NFPA 1 and IFC, which are the basis for municipal and regional electrical and fire codes. In addition, UL 9540 is currently referenced in NFPA 855, the new installation standard for energy storage systems that is under development. Establishing compliance for an energy storage system to UL 9540 will help to ease restrictions on installations at sites subject to AHJ approval.

Utility grid interaction is also addressed in UL 9540 as energy storage systems, by definition in UL 9540 are intended for supply energy to a local or utility grid or both. UL 9540 makes reference to UL 1741 for power conditioning systems, and its recent supplement SA of UL 1741 is intended to address grid support utility interactive inverters that make up part of an energy storage system.

Fire detection and suppression are a critical consideration for energy storage systems, especially those that utilize battery energy storage. UL 9540 currently requires that a fire safety analysis be conducted (typically done fire protection consultants) to determine the need for, and type of detection and suppression system to be provided either as components installed within the energy storage system or to be identified and described in sufficient detail in the installation instructions. These devices are to be installed in accordance with the applicable fire code regulations. The next edition of UL 9540, tentatively to be published in 2019, will make further reference to the recent fire codes, which have been updated to better address energy storage systems and will also reference the new large scale fire test method developed by UL in UL 9540A for commercial battery energy storage systems.

In addition to construction criteria, there is testing criteria in UL 9540 that are essentially a check of the safe operation of the system. A majority of the testing criteria are located within the major component references such as UL 1973 for the stationary batteries. To get a better understanding of the tests that the battery system portion are required to comply with, a review of UL 1973 is necessary.
Stationary Battery Safety Standard - UL 1973 Overview

UL 1973 is well known and globally accepted safety standard for stationary batteries and has been recently revised to the 2nd edition in February 2018. A UL 1973 battery system is ultimately a component of a UL 9540 energy storage system, and not a replacement of evaluating a full ESS. UL 1973 is technology agnostic but does have a number of specific criteria for different technologies of batteries such as lithium ion, sodium beta batteries and flow batteries.

UL 1973 is structured in a similar manner as UL 9540 as it contains both construction criteria, and testing as well as labeling, marking, and user instruction requirements. As with UL 9540, UL 1973 has requirements for a safety analysis of the battery system, to ensure that the BMS and other protections provided with the battery maintain the battery system in a safety state including ensuring that the battery cells do not operate outside of their specified operating regions for voltage, current and temperature under charging, discharging and other conditions of use. The battery tests in UL 1973 are grouped into electrical, mechanical environmental tests and required per the evaluation of the stationary battery.

UL 1973 is a standard that can be used for most battery technologies and for capacitor and hybrid capacitor and battery systems. UL 1973 references several standards for cell and capacitor criteria, and also contains quite a bit of technology specific criteria that include cell test programs for secondary lithium cells. UL 1973 also has several appendices that have specific criteria for sodium beta technologies such as sodium sulfur and sodium nickel chloride and flow batteries such as vanadium redox and zinc bromine.

<table>
<thead>
<tr>
<th>Figure 2 – Hierarchy of UL Battery Standards for Energy Storage Systems (UL 9540)</th>
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<tbody>
<tr>
<td><strong>Energy Storage Component</strong></td>
</tr>
<tr>
<td>Cell</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Cell</td>
</tr>
<tr>
<td>Monobloc battery with relief valve and/or flame arrestors</td>
</tr>
<tr>
<td>Stack</td>
</tr>
</tbody>
</table>
**Test Method for Fire Propagation in Battery Energy Storage Systems - UL 9540A Overview**

UL 9540A, “Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems” was developed by UL to address a requirement in the International Code Council’s International Fire Code and a similar anticipated requirement in the installation standard, NFPA 855, Installation of Energy Storage Systems for large scale fire testing. Fire Code and building codes have placed strict limitations on the size and quantity of energy storage systems as well as separation distances between systems and between systems and structures that can be installed in mixed use occupancies. These limitations on size are based upon energy limits and are technology dependent. The large scale fire testing can be used to assess the risk and probability of fire propagation in order to reduce separation distances, increase size (energy) of systems to be installed, and show effectiveness of fire suppression systems.

The results from the UL 9540A test method is intended to address the following key areas of concern identified by building code and fire code officials: 1) the appropriateness of the battery energy storage system (BESS) installation instructions with regard to separation distances and location of cabling to and from the system, 2) installation ventilation requirements, 3) effectiveness of fire protection and deflagration mitigation strategies, and 4) information necessary for fire service strategy and tactics in the event of a fire involving the BESS.

The test method has several different levels of testing. The first level, is the cell level testing, whose purpose is to determine a method for consistently creating a thermal runaway condition in a cell and for collecting temperature to venting, collecting and identify gases vented from the cell upon completion of the cell level testing, the testing moves on to the module level testing. This level is also an information gathering step. One or more cells in a module are driven into thermal runaway, and the effects of the fire to lead to propagation in the module is evaluated. The same procedure for failing cells at the module level is then replicated at the unit level, with one module that is located within the energy storage system, where there is the potential for worse case conditions. For the unit level tests on initiating battery energy storage system BESS unit representative of what is to be installed in the field, is subjected to the cell failing in one of its modules, while the other modules. A final installation level test can be done in cases where fire mitigation and suppression devices are installed in addition to the BESS unit to mitigate/suppress the fire & deflagration propagation hazard.

The need for large scale fire testing assumes that something could go wrong even with protection controls in place due to the quantities of energy stored within large BESS systems.
Evaluation for Repurposing Batteries, UL 1974

Another area of standardization that UL is attempting is in the area of repurposed batteries. Batteries for electric vehicles, which are primarily lithium ion battery systems, tend to be rather complex and expensive parts of the vehicle, and with any battery, energy is lost over time due to use and other factors. Batteries procured from vehicles may still have about 80 percent useful energy left in it. If the used battery is still determined to be safe for use in another application, this provides a possible second market for these batteries.

The entities that obtain these used batteries with plans to use them for other applications need to have a process in place for establishing the health of the battery and some processes for sorting and grading cells and modules if disassembled from the battery for reconfiguring for another application.

Unlike the other standards described in this paper, UL 1974 is not a product safety standard, but rather a process standard. It identifies key items to be considered for this type of process, provides recommended testing and evaluation procedures that should be in place, and then finally references end product standards that the used batteries would need to comply with in order to be considered for repurposing. The end result will be for repurposing facilities to be able to certifying their process & procedures to be a UL 1974 certified repurposing facility.
**How Codes Impact Energy Storage – USA example**

**National Electric Code, NFPA 70**

The 2017 edition of NFPA 70, National Electric Code (NEC) contained new articles impacting energy storage systems. The most critical one, was the new article 706 for energy storage systems. Article 706 was intended to put requirements for energy storage systems in one location of the NEC. Requirements in Article 706 borrowed from several different areas of the NEC such as Article 480 for storage batteries, Article 690 for photovoltaic and others along with added criteria to better address various technologies (especially various types of batteries) being used for energy storage.

Article 706 requires that the major components of the energy storage system by listed, which is defined as being maintained on a published list by a third party indicating compliance to a suitable and accepted set of criteria such as a safety standard and that is subjected to periodic production inspections. It also indicates that self-contained systems can be listed as a system. In addition, UL 9540 is referenced in Article 706 as an informative reference that can be used to evaluate energy storage systems. UL 1973 is also referenced in the NEC as a standard that can be used to evaluated stationary batteries. Article 706 provides specific criteria for battery energy storage systems and does include requirements for flow batteries and includes other types of energy storage systems although nothing specific to these other types of systems are in the article at this time.

**International Fire Code**

The 2018 edition of the International Code Council’s IFC, was updated to better address energy storage system technologies, with section 1206 provided for energy storage system requirements. As noted in Section 1206 Table 1206.2, there are threshold quantities based upon energy limits, which indicate when permitting of system are required and which must meet the requirements outlined in 1206. The ICC International Fire Code has restrictions to the amount of energy and their distances spaced from each other. Separation distances are rather strict, with separation distances between individual BESSs and between BESSs and structure walls need to be at least 3 ft to prevent system to system propagation.

There are exceptions for the limitations outlined in IFC such as exceptions to the threshold quantities of Table 1206.2 or ability to install technologies not identified in the table through a hazard mitigation analysis. Sizes of energy storage system units can be increased beyond the energy limitations through Listing and through large scale fire testing. The codes also require listing to UL 9540 for energy storage systems and UL 1973 for battery systems. Most importantly, separation distances can be reduced and maximum quantities increased through large scale fire testing approved by the local authorities. Figure 4 below provides a brief overview of the limitations on energy storage systems in the 2018 IFC and noted exceptions.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Limitation Imposed</th>
<th>Exceptions</th>
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</table>
| Threshold Quantities that must comply with IFC requirements of Section 1206:  
  - lead acid or nickel  
  - lithium, sodium and flow  
  - other technologies | 70 kWh  
  20 kWh  
  10 kWh | Hazard mitigation analysis per 1206.2.3 |
| Size of Individual Array (BESS unit) | 50 kWh |  
  - Lead acid and nickel cadmium technologies,  
  - 150 kWh for other technologies if Listed  
  - > 150 kWh for other technologies if Listed and if LSF testing & AHJ approval |
| Separation distances between BESS arrays or between arrays and structure | ≥ 3 ft |  
  - Lead acid and nickel cadmium technologies  
  - Smaller separation distances for other technologies if Listed and if LSF testing & AHJ approval |

AHJ – authority having jurisdiction  
LSF – large scale fire testing, which can be addressed by the 9540A test method  
FF – fire fighter
Standard for Installation of Energy Storage Systems, NFPA 855

The purpose of the NFPA 855 installation standard for energy storage systems, is to help with installation of energy storage systems and all requirements for installing them within buildings.

NFPA 855 will closely match what is in or proposed for the ICC IFC. At some point, when NFPA 855 is published, the IFC will refer to NPFA 855 for most of the installation criteria for energy storage system criteria rather than including this information in the IFC separately. This would also be true for other codes and regulations.

Similar to the National Electric Code and the IFC, NFPA 855 refers to the UL 9540 standard and requires listing of energy storage systems. The draft NFPA 855 also mirrors what is in the IFC for sizes and limits on installations based upon energy limits and provides exceptions to these limits based upon large scale fire testing.

IEC Developments

Requirements that address energy storage systems globally, are still under development. IEC 62933 Series will contain parts that will address the safety of electrical energy storage systems. With many parts still remaining under development, there are parts currently published to address testing methods, guidance on environmental issues, and considerations for grid-integration. Parts still under development will address planning and installation, and safety considerations related to electrical energy storage systems composed of batteries. As the global requirements utilized many of the methodologies noted in UL 9540, a path to future harmonization is foreseeable. As UL is both a convening and participating organization for the IEC committees impacting IEC 62933 series, UL will share pertinent insight and impact on the international requirements as they become available.

Summary

UL has been involved in standard development, evaluation, testing, and certification of battery energy storage systems. This work has been acknowledged by many in the safety world as having a positive global impact to public safety and can be applied in many parts of the world including South Africa and Sub-Sahara Africa.

As noted in this presentation, several standards could immediately be of value namely UL 9540, UL 1973, UL 9540A, and UL 1974. In addition, the installation code system of United States, in combination with the existing system(s) in South Africa and/or Sub-Sahara Africa, could serve as a model system to enable any battery energy storage system project to go through a recognizable level of due diligence. This can also aid in obtain of insurance as well maintain public assurance as these new system move closer to living and working environments of people.

Just like UL has been involved with the mass adoption of electricity being introduced to the world in the early 1900s, we will also carry on the public safety mission with other newer technologies. As the story of stored energy continues, UL will continue to serve leading markets and manufacturers to develop safe and reliable product and environments.