



UL 1973

STANDARD FOR SAFETY

Batteries for Use in Light Electric Rail (LER)
Applications and Stationary Applications

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UL Standard for Safety for Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications, UL 1973

First Edition, Dated February 15, 2013

Summary of Topics

Revisions have been issued for UL 1973 to add a future effective date to Sections 5.7, 5.8.2, 11, 17, 18, 19, 28, 35, and 40. Nothing else has been changed in the standard.

Text that has been changed in any manner or impacted by UL's electronic publishing system is marked with a vertical line in the margin. Changes in requirements are marked with a vertical line in the margin and are followed by an effective date note indicating the date of publication or the date on which the changed requirement becomes effective.

The requirements are substantially in accordance with Proposal(s) on this subject dated July 13, 2012 and November 30, 2012.

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The following table lists the future effective dates with the corresponding reference.

Future Effective Date	References
February 15, 2016	Sections 5.7, 5.8.2, 11, 15, 17, 18, 19, 28, 33, 35, 37, and 40



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**Standard for Batteries for Use in Light Electric Rail (LER) Applications and
Stationary Applications**

First Edition

February 15, 2013

This ANSI/UL Standard for Safety consists of the First Edition including revisions through July 3, 2013.

The most recent designation of ANSI/UL 1973 as an American National Standard (ANSI) occurred on February 15, 2013. ANSI approval for a standard does not include the Cover Page, Transmittal Pages, Title Page, or effective date information.

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INTRODUCTION

1 Scope

1.1 These requirements cover electric energy storage systems as defined by this standard for use as energy storage for stationary applications such as for PV, wind turbine storage or for UPS, etc. applications. These systems are to be installed in accordance with the National Electric Code, ANSI/NFPA 70 or other applicable installation codes.

1.2 These requirements also cover electric energy storage systems (EESS) as defined by this standard for use in light electric rail (LER) applications and stationary rail applications such as rail substations. These systems are intended for installation within either the rail car or within a sheltered stationary location such as a rail substation. These electric energy storage systems may utilize regenerative braking from the trains as a source of energy for recharging and are intended for direct or indirect connection to the rail power lines. These electric energy storage systems are intended for balancing loads during peak hours, serving as an energy storage device during regenerative braking of the trains, and as a source of emergency power to move trains to the nearest station during power outages.

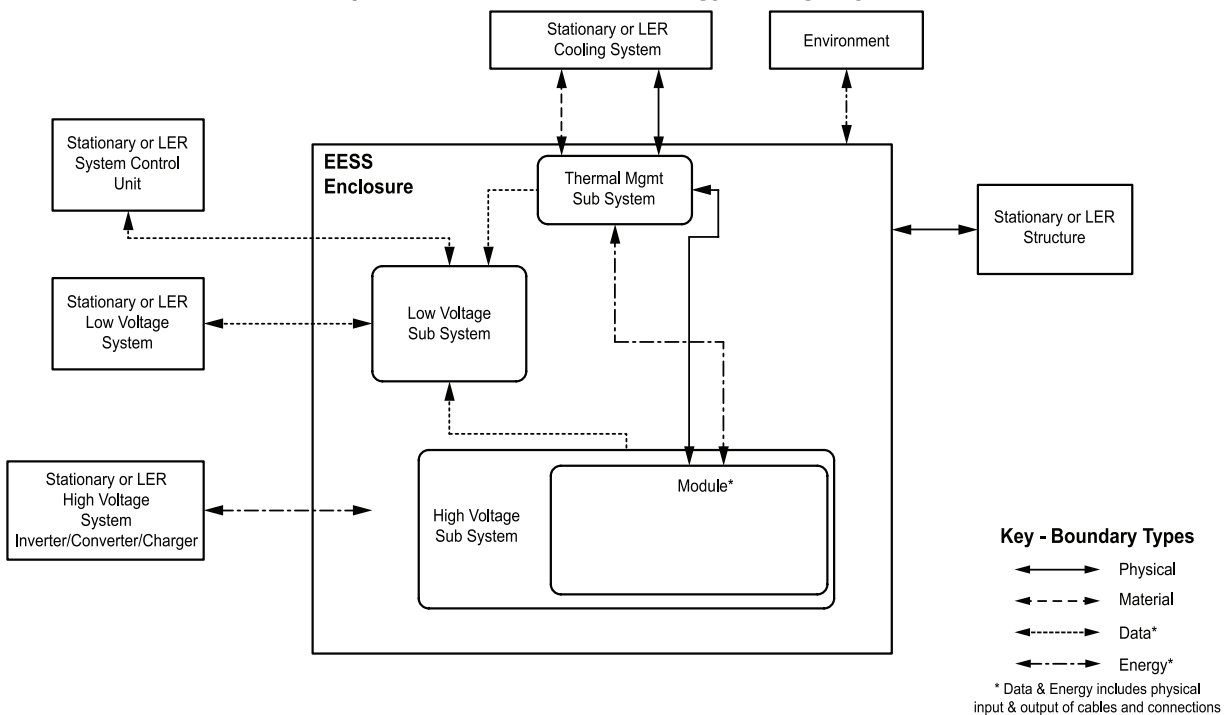
1.3 Appendix B of this standard includes requirements specific to sodium-beta type technologies. Appendix C of this standard includes requirements specific to flowing electrolyte technologies.

1.4 This standard evaluates the electric energy storage system's ability to safely withstand simulated abuse conditions. This standard evaluates the system based upon the manufacturer's specified charge and discharge parameters.

1.5 This standard does not evaluate the performance (i.e. capacity measurements under various discharge conditions) or reliability (i.e. capacity measurements under various environmental conditions) of these devices.

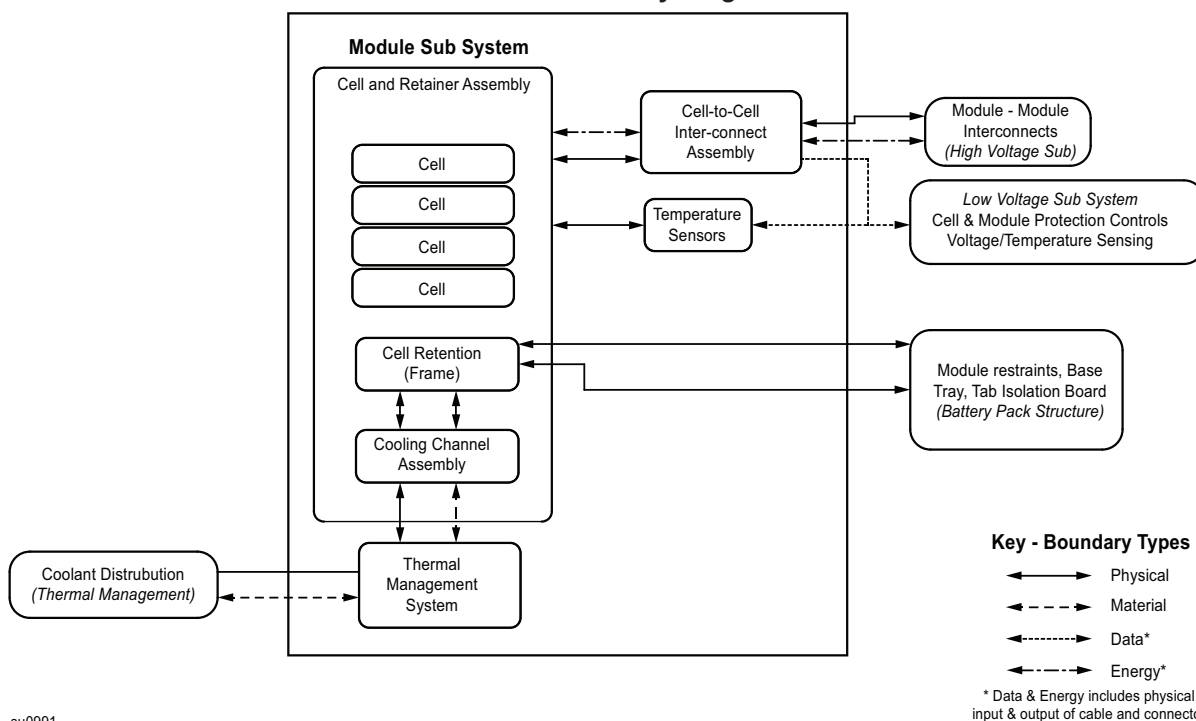
1.6 Figure 1.1 is a boundary diagram example for an electric energy storage system for this application. Figure 1.2 is a boundary diagram example for a module for this application.

Figure 1.1
Components of an electric energy storage system



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Figure 1.2
Module – boundary diagram



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2 Units of Measurement

2.1 Values stated without parentheses are the requirement. Values in parentheses are explanatory or approximate information.

3 References and Components

3.1 Any undated reference to a code or standard appearing in the requirements of this outline of investigation shall be interpreted as referring to the latest edition of that code or standard.

3.2 A component of a product covered by this standard shall comply with the requirements for that component. See Appendix A for a list of standards covering components generally used in the products covered by this standard.

4 Glossary

4.1 BATTERY – A general term for either a single cell or a group of cells connected together either in a series and/or parallel configuration.

4.2 BATTERY PACK – Batteries that are ready for use, contained in a protective enclosure, which may or may not contain protective devices, cooling systems and monitoring circuitry. Although batteries may be the dominant energy storage device in the pack, the battery pack may include electrochemical capacitors as a type of hybrid pack.

4.3 CAPACITOR PACK – Electrochemical capacitors that are ready for use in an electric energy storage system, contained in a protective enclosure, with or without protective devices, cooling systems, and monitoring circuitry. Although electrochemical capacitors may be the dominant energy storage device in the pack, the capacitor pack may include batteries as a type of hybrid pack.

4.4 CAPACITY, RATED (C_n) – The total number of ampere-hours that can be withdrawn from a fully charged battery at a specific discharge rate to a specific end-of-discharge voltage (EODV) at a specified temperature as declared by the manufacturer.

4.5 CASING – The container that directly encloses and confines the contents of a cell or electrochemical capacitor.

4.6 CELL – The basic functional electrochemical unit containing an assembly of electrodes, electrolyte, separators, container, and terminals. It is a source of electrical energy by direct conversion of chemical energy.

4.7 CELL BLOCK – One or more cells connected in parallel.

4.8 CHARGING – The application of electric current to battery or capacitor terminals, which results in a Faradic reaction that takes place within the battery that leads to stored electro-chemical energy or in the case of the capacitor, due to electrical charge being stored without a chemical reaction taking place.

4.9 CHARGING, CONSTANT CURRENT (CC) – Charging mode where current is held constant while charging voltage is allowed to vary.

4.10 CHARGING, CONSTANT VOLTAGE (CV) – Charging mode where voltage is held constant while charging current is allowed to vary.

4.11 DUT – Device under test.

4.12 **ELECTRIC ENERGY STORAGE SYSTEM** – Consists of a pack and external controls and circuitry related to the pack such as cooling systems, disconnects or protection devices external to the pack.

4.13 **ELECTROCHEMICAL CAPACITOR** – An electric energy storage device where electrical charge is typically stored as a result of non-Faradaic reactions at the electrodes. (A subset of electrochemical capacitors referred to as an "asymmetric" type have non-Faradaic reactions at one electrode and Faradaic reactions at the other electrode.) A highly-porous surface of the electrodes increases the surface area for holding charge resulting in much larger capacitance and energy density. Electrochemical capacitors differ from common electrolytic capacitors in that they employ a liquid rather than a solid dielectric with charge occurring at the liquid-solid interface of the electrodes when a potential is applied. Some other common names for an electrochemical capacitor are "double layer capacitor", "ultracapacitor", "electrochemical double layer capacitor", "super capacitor", and "EDLC".

4.14 **ENCLOSURE** – The protective outer cover of the pack or electric energy storage system that provides mechanical protection to the pack/system's contents.

4.15 **END-OF-DISCHARGE VOLTAGE (EODV) (Cell)** – The voltage, under load, of the cell at the end of discharge. The EODV may be specified by the manufacturer, as in the case of a voltage-terminated discharge typical for lithium ion chemistries.

4.16 **EXPLOSION** – A violent release of energy that produces projectiles or a pressure wave from the DUT and results in DUT contents being forcibly expelled through a rupture in the enclosure or casing.

4.17 **FIRE** – The sustained combustion of the DUT's contents as evidenced by flame, heat, and charring or other damage of materials.

4.18 **FLOWING ELECTROLYTE BATTERY** – A rechargeable battery that stores its active materials, in the form of liquid aqueous electrolytes, external to the battery. The electrolytes, which serve as energy carriers, are pumped through two half cells separated by an ion-permeable separator, which provides separation of the two electrolytes while still allowing for the passage of ions during charging and discharging. Charging and discharging results in a chemical reduction reaction in one electrolyte and an oxidation reaction in the other electrolyte. Ions selectively pass through the separator membrane to complete the redox reaction. When in use the electrolytes are continuously pumped in a circuit between reactor and storage tanks. Two commercially available flowing electrolyte batteries technologies, the zinc bromine and the vanadium redox types, are described below:

a) **ZINC BROMINE** – A flowing electrolyte battery technology that has zinc at the negative electrode and bromide at the positive electrode with an aqueous solution containing zinc bromide and other compounds contained in two separate reservoirs. During charging, energy is stored as zinc metal within the cell and polybromide in the cathode reservoir. During discharge, the zinc is oxidized to zinc oxide and the bromine is reduced to bromide.

b) **VANADIUM REDOX** – A flowing electrolyte battery technology that contains vanadium salts in various stages of oxidation in a sulfuric acid electrolyte. Charging and discharging the battery changes the oxidation state of the vanadium in the electrolyte solutions.

4.19 **FULLY CHARGED** – An electric energy storage system, pack, module or cell which has been charged to its full state of charge (SOC) as specified by the manufacturer.

4.20 **FULLY DISCHARGED** – An electric energy storage system, pack, module or cell, which has been discharged to its end-of-discharge voltage (EODV) as specified by the manufacturer.

4.21 HAZARDOUS VOLTAGE – A sinusoidal voltage exceeding 42.4 V_{peak} or 60 V_{dc}.

4.22 INSULATION LEVELS – The following are levels of electrical insulation:

- a) BASIC INSULATION – insulation to provide basic protection against electric shock.
- b) DOUBLE INSULATION – Insulation comprising both basic insulation and supplementary insulation.
- c) FUNCTIONAL INSULATION – Insulation that is necessary only for the correct functioning of the equipment. Functional insulation by definition does not protect against electric shock. It may, however, reduce the likelihood of ignition and fire.
- d) REINFORCED INSULATION – Single insulation system that provides a degree of protection against electric shock equivalent to double insulation under the conditions specified in this standard. The term “insulation system” does not imply that the insulation has to be in one homogeneous piece. It may comprise several layers that cannot be tested as basic insulation and supplementary insulation.
- e) SUPPLEMENTARY INSULATION – Independent insulation applied in addition to basic insulation in order to reduce the risk of electric shock in the event of a failure of the basic insulation.

4.23 LEAKAGE – A condition where liquid escapes through an opening in a designed vent or through a rupture or crack or other unintended opening and is visible external to the device under test.

4.24 LIGHT ELECTRIC RAIL (LER) – A term used to specify a commuter train that obtains all of its motive energy from electricity.

4.25 LIMITED POWER CIRCUIT – A circuit supplied by a power source that meets SELV limits and whose power and current are further limited in accordance with the Limited Power Source Test of the Standard for Household and Commercial Batteries, UL 2054. A limited power source is equivalent to a Class 2 circuit in accordance with Article 725 of the National Electrical Code, ANSI/NFPA 70. A similar concept to limited power is the term “low-voltage limited energy” (LVLE) as defined in Section 16 of the Standard for Electric-Battery-Powered Industrial Trucks, UL 583.

4.26 LITHIUM ION CELL – A rechargeable cell where electrical energy is derived from the insertion/extraction reactions of lithium ions between the anode and the cathode. The lithium ion cell has an electrolyte that typically consists of a lithium salt and organic solvent compound in liquid or gel or solid form and has either a hard metal casing or a flexible polymeric pouch casing.

4.27 MAINS SUPPLY (AC) – An ac power distribution system external to the equipment for supplying power to ac powered equipment. Examples of ac mains supply include public or private utilities and equivalent sources such as motor-driven generators and uninterruptible power supplies.

4.28 MANUFACTURING PRODUCTION LINE TESTING – Testing at the manufacturer’s facilities used as a manufacturing check of their production. Depending upon the testing, it either can be a 100% production test, or can be a periodic check or sampling of production. This testing is sometimes referred to as routine testing.

4.29 MAXIMUM WORKING VOLTAGE – The highest voltage to which the insulation or component under consideration is or can be subjected to when the equipment is operated under conditions of normal use.

4.30 **MODULE** – A subassembly consisting of a group of cells or electrochemical capacitors connected together either in a series and/or parallel configuration (sometimes referred to as a block) with or without protective devices and monitoring circuitry. A module is a component of an electric energy storage system. See Figure 1.2.

4.31 **MONOBLOC BATTERY** – A battery design that contains a common pressure vessel construction, a single vent assembly and shared hardware.

4.32 **MOSOC** – Maximum operational state of charge. Refer to 6.1.

4.33 **NICKEL CELL** – A general term for a nickel cadmium or nickel metal hydride rechargeable cell that has a nickel hydroxide positive electrode and either a cadmium metal or metal hydride negative electrode and that has a liquid alkaline (i.e. KOH) electrolyte.

4.34 **NORMAL OPERATING REGION** – That region of voltage, current, and temperature within which a cell or electrochemical capacitor can safely be charged and discharged repetitively throughout its anticipated life. The manufacturer specifies these values, which are then used in the safety evaluation of the device and may vary as the device ages.

4.35 **PROTECTIVE DEVICES, ACTIVE** – Devices provided to prevent hazardous conditions that require electrical energy in order to operate. An example of an active control would be a battery management system (BMS).

4.36 **PROTECTIVE DEVICES, PASSIVE** – Devices provided to prevent hazardous conditions that do not require electrical energy in order to operate. An example of a passive protective device would be a fuse.

4.37 **ROOM AMBIENT** – Considered to be a temperature in the range of $25 \pm 5^\circ\text{C}$ ($77 \pm 9^\circ\text{F}$).

4.38 **RUPTURE** – A mechanical failure of the DUT's enclosure/casing from either internal or external causes, that results in spillage and/or exposure of internal contents of the DUT, but does not result in projectiles and violent energy release, which occur during an explosion.

4.39 **SAFETY EXTRA LOW VOLTAGE CIRCUIT (SELV)** – A circuit that exhibits voltages, which are safe to touch both under normal operating conditions and after a single fault. The voltage limits of Table 4.1 shall not be exceeded. An extra low voltage (ELV) is equivalent to SELV under normal conditions (not single fault) only.

Table 4.1
SELV voltage limits

Voltage limits	
Normal	Single Fault
Open circuit voltage with generally sinusoidal shape of 42.4 V peak or 60 Vdc	Open circuit voltage with generally sinusoidal shape of 42.4 V peak or 60 Vdc with excursions up to 71 V peak or 120 Vdc for periods up to 200 ms

4.40 SODIUM-BETA (HIGH TEMPERATURE) CELLS – Cells that utilize metallic sodium and ceramic beta-alumina solid electrolyte and that operate at elevated temperatures. The following are two commercial technologies under this group:

a) SODIUM NICKEL CHLORIDE CELL – A rechargeable cell that has sodium as its negative electrode, a positive electrode that may consist of nickel, nickel chloride or sodium chloride and a ceramic beta-alumina solid electrolyte. The normal operation of the cell is within a temperature range of 270 – 350°C (518 – 662°F) so that the active materials are in a molten state and to ensure ionic conductivity.

b) SODIUM/SULFUR CELLS – A rechargeable cell that has sodium as its negative electrode, a positive electrode that consists of sulfur, and a ceramic beta alumina electrolyte. The normal operation of the cells is within a temperature range of 310 – 370°C (590 – 698°F) so that the active materials are in a molten state and to ensure ionic conductivity.

4.41 STATE OF CHARGE (SOC) – The available capacity in an electric energy storage system, pack, module or cell expressed as a percentage of rated capacity.

4.42 TOXIC VAPOR RELEASE – A release of vapor(s) in a concentration in excess of the Occupational Safety and Health Administration (OSHA) 8-h time-weighted-average (TWA) permissible exposure limit, which corresponds to the National Institute of Safety and Health (NIOSH) 10 h per day, 40 h per week permissible exposure limits.

4.43 VENTING – A condition when the cell electrolyte and/or battery/capacitor solvent is emitted as vapor, smoke or aerosol from a designed vent or through a sealing edge.

CONSTRUCTION

5 General

5.1 Non-metallic materials

5.1.1 Polymeric materials employed for enclosures shall comply with the requirements as outlined in Table 4.1 Path III of the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C except as modified by this standard.

Exception No. 1: Polymeric materials utilized for light electric rail (LER) enclosures for motive applications shall have a minimum flammability of V-1 or better, in accordance with the Standard for Tests for Flammability of Plastic Materials for Parts in Devices and Appliances, UL 94 if intended for building into an enclosure or compartment within the train.

Exception No. 2: LER enclosure parts for motive applications may alternatively be evaluated to the 20 mm end-product flame tests in accordance with the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

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5.1.2 The factors taken into consideration when an enclosure is being judged are as follows. For a nonmetallic enclosure all of these factors are to be considered with respect to thermal aging. Dimensional stability of a polymeric enclosure is addressed by compliance to the mold stress relief distortion test.

- a) Resistance to impact;
- b) Crush resistance;
- c) Abnormal operations;
- d) Severe conditions; and
- e) Mold-stress relief distortion.

5.1.3 The polymeric materials employed as enclosures and insulation shall be suitable for anticipated temperatures encountered in the intended application. Pack enclosures shall have a Relative Thermal Index (RTI) with impact suitable for temperatures encountered in the application but no less than 80°C (176°F), as determined in accordance with the Standard for Polymeric Materials – Long Term Property Evaluations, UL 746B.

5.1.4 The pack enclosure materials intended to be exposed to sunlight in the end use application shall comply with the UV Resistance and the Water Exposure and Immersion tests in accordance with the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

5.1.5 Polymeric materials used as direct support for live parts other than those circuits determined non-hazardous (i.e. limited power circuits) shall comply with the insulation requirements of the Standard for Polymeric Materials – Use in Electrical Equipment Evaluations, UL 746C.

Exception: Insulation materials that meet the criteria outlined in the Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1, clause 4.7.3.3 "Materials for components and parts outside of fire enclosures" or clause 4.7.3.4 "Materials for components and parts inside of fire enclosures" are considered acceptable.

5.1.6 Gaskets and Seals relied upon for safety shall be determined suitable for the temperatures they are exposed to and other conditions of use. Compliance is determined by the applicable tests of the Standard for Gaskets and Seals, UL 157.

5.2 Metallic parts resistance to corrosion

5.2.1 Metal pack enclosures shall be corrosion resistant. A suitable plating or coating process can achieve corrosion resistance. Additional guidance on methods to achieve corrosion protection can be found in the Standard for Enclosures for Electrical Equipment, Environmental Considerations, UL 50E.

5.2.2 Conductive parts in contact at terminals and connections shall not be subject to corrosion due to electrochemical action. Combinations above the line in Table D.1 of Appendix D shall be avoided.

5.3 Enclosures

5.3.1 The enclosure of an electric energy storage system shall have the strength and rigidity required to resist the possible physical abuses that it will be exposed to during its intended use, in order to reduce the risk of fire or injury to persons. Compliance is determined by the tests of this standard.

5.3.2 A tool providing the mechanical advantage of a pliers, screwdriver, hacksaw, or similar tool, shall be the minimum mechanical capability required to open the enclosure.

5.3.3 Openings in the enclosure shall be designed to prevent inadvertent access to hazardous parts. Compliance is determined by the Tests for Protection Against Access to Hazardous Parts Indicated by the First Characteristic Numeral, Clause 12 of the Standard for Degrees of Protection Provided by Enclosures (IP Code), ANSI/IEC 60529, for a minimum IP rating of IP2X or IPXXB. (Evaluation per the Standard for Degrees of Protection Provided by Enclosures (IP Code), ANSI/IEC 60529, Clause 12, consists of the use of the IEC articulate probe applied with a force of 10 N $\pm$ 10%).

5.3.4 Openings in the enclosure shall be constructed to prevent accumulation of flammable gases that could lead to a hazardous condition from concentrations of hydrogen gas due to electrolysis of aqueous electrolytes for applicable battery technologies, such as vented or valve regulated lead acid and nickel batteries and applicable electrochemical capacitor technologies, greater than 25% of the LFL of hydrogen (equivalent to 1% concentration in a volume of air). Ventilation openings shall have a minimum opening area of:

$$A = 0.005NC_5 \text{ (cm}^2\text{)}$$

Where:

A = Total cross sectional area of ventilation holes required (cm²)

N = Number of cells in battery

C_5 = Capacity of battery at the 5-h rate (Ah)

Exception: The area of ventilation openings can be reduced if it can be demonstrated that there is sufficient ventilation within the battery to prevent hydrogen accumulations above 25% of the LFL of hydrogen.

5.3.5 Packs intended for installation where they may be exposed to moisture either through rain, splashing water or immersion shall be evaluated for their intended resistance to ingress of moisture in accordance with the Standard for Degrees of Protection Provided by Enclosures (IP Code), ANSI/IEC 60529 or as outlined in the National Electrical Code, ANSI/NFPA 70, Article 110, and the Standard for Enclosures for Electrical Equipment, Environmental Consideration, UL 50E, or the Standard for Enclosures for Electrical Equipment (1000 Volts Maximum), NEMA 250. See also Section 32.

5.4 Wiring and terminals

5.4.1 General

5.4.1.1 Wiring shall be insulated and acceptable for the purpose, when considered with respect to temperature, voltage, and the conditions of service to which the wiring is likely to be subjected within the equipment.

5.4.1.2 A wiring splice or connection shall be mechanically secure and shall provide electrical contact without strain on connections and terminals. Wiring shall be secured and routed away from sharp edges or parts exceeding insulation. Openings in compartments through which insulated wiring is routed shall be smooth and well-rounded or provided with protective insulating bushings or grommet to prevent abrasion. Wiring connections between various parts of a battery module/pack and accessories shall be routed and secured to prevent the potential for short circuit conditions to occur.

5.4.1.3 An uninsulated live part, including a terminal, shall be secured to its supporting surface by a method other than friction between surfaces so that it will be prevented from turning, shifting in position, or creating short circuit.

5.4.1.4 An external battery terminal shall be designed to prevent inadvertent shorting. An external terminal shall be designed to prevent inadvertent misalignment or disconnection when installed in its end use application.

5.4.1.5 External non-detachable cords and leads that are accessible in the end use installation shall be provided with strain relief that prevents strain to internal conductors under pull and push-back conditions. Compliance is determined by the tests of 22.4 and 22.5.

5.4.1.6 Plugs and receptacles shall be rated for the intended voltage, current, temperature, and if applicable, for disconnect under load conditions.

5.4.1.7 Electric energy storage system cables shall be rated for their anticipated service including voltage, current, temperature and environment. External cords for hazardous voltage circuits shall be jacketed to prevent wear to internal conductors and rated and provided with insulation suitable for the intended applications.

5.4.1.8 In multiway plugs and sockets, and wherever shorting could otherwise occur, means shall be provided to prevent contact between parts in SELV circuits or parts at hazardous voltage due to loosening of a terminal or breaking of a wire at a termination. Compliance is checked by inspection, by measurement and, where necessary, by the following test:

- a) A force of 10 N (2.25 lbf) is applied to the conductor near its termination point. The conductor shall not break away or pivot on its terminal to the extent that spacings are reduced below the values specified in 5.5.

5.4.1.9 Wiring compartments and wiring terminals provided for connection of the electric energy storage system to external circuits shall be constructed as outlined below:

- a) A field wiring compartment in which supply connections are to be made shall be located so that the connections will be accessible for inspection after the unit is installed as intended.
- b) A knockout in a sheet-metal enclosure shall be secured and shall be removable without undue deformation of the enclosure. The knockout shall be surrounded by a flat surface to accommodate seating of a conduit bushing or locknut of the appropriate size.
- c) An outlet box, terminal box, wiring compartment, in which field connections are made shall be free from any sharp edges including screw threads, a burr, a fin or moving part of the like that may abrade the insulation on conductor or otherwise damage wiring.
- d) A field wiring terminal or lead shall be rated for the connection of a conductor or conductors having a minimum ampacity rating of 135% of the rating of the unit.
- e) The distance between the end of the connection point of a field installed wire and the wall of the enclosure toward which the wire is to be directed shall be in accordance with Table 312.6 (A) of the National Electric Code, ANSI/NFPA 70.

5.4.2 Beads and ceramic insulators

5.4.2.1 Beads and similar ceramic insulators on conductors shall:

- a) Be so fixed or supported that they cannot change their position in such a way that a hazard would be created; and
- b) Not rest on sharp edges or sharp corners.

5.4.2.2 If beads are located inside flexible metal conduits, they shall be contained within an insulating sleeve, unless the conduit is mounted or secured in such a way that movement in normal use would not create a hazard. Compliance is checked by inspection and, where necessary, by the following test:

- a) A force of 10 N (2.25 lbf) is applied to the insulators or to the conduit. The resulting movement, if any, shall not create a hazard in the meaning of this standard.

5.5 Spacings and separation of circuits

5.5.1 Electrical circuits within the pack at opposite polarity shall be provided with reliable physical spacing to prevent inadvertent short circuits (i.e. electrical spacings on printed wiring boards, physical securing of un-insulated leads and parts, etc.). Insulation suitable for the anticipated temperatures and maximum voltages shall be used where spacings cannot be controlled by reliable physical separation.

5.5.2 Electrical spacings in circuits shall be based upon the grade of insulation required as outlined in the Grade of Insulation section of the Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1, and shall comply with the creepage and clearance requirements of the Clearances, Creepage Distances and Distances Through Insulation section of the Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1 for the appropriate pollution degree of the intended environment (see the Pollution Degrees section of the Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1).

Exception No. 1: As an alternative to these spacing requirements, the spacing requirements in the Standard for Insulation Coordination Including Clearances and Creepage Distances For Electrical Equipment, UL 840, may be used. For determination of clearances, a dc source such as a battery does not have an overvoltage category as outlined in the section for Components of the Standard for Insulation Coordination Including Clearances and Creepage Distances For Electrical Equipment, UL 840 unless charged through an ac mains connected rectifier, then the overvoltage category should be the same as that required for the rectifier unless the rectifier uses galvanic isolation. If galvanic isolation is employed, then the overvoltage category can be reduced to the next lower overvoltage category. The anticipated pollution degree is determined by the design and application of the electrical energy storage system or subassembly under evaluation.

Exception No. 2: As an alternative to the clearance values outlined in the Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1, the clause for Clearances, Creepage Distances and Distances Through Insulation, the alternative method for determining minimum clearances in the Annex for Alternative Method for Determining Minimum Clearances, Annex G, of the Standard for Information Technology Equipment – Safety – Part 1: General Requirements, UL 60950-1 may be applied.

Exception No. 3: As an alternative to these spacing requirements, the spacing requirements of Table 5.1 may be applied instead. When using this table, maximum working voltages of circuits can be determined through the test of Section 21. See the note in Table 5.1 regarding adjustment for spacings where double or reinforced insulation is required.

Table 5.1
Electrical Spacings

Circuit ratings	Minimum spacings ^a	
	Through air	Over surface
	Between parts of opposite polarity, live and non-current carrying parts and live and ground connections	Between parts of opposite polarity, live and non-current carrying parts and live and ground connections
V	mm (in)	mm (in)
30 – 50 ^b	1.6 (1/16)	1.6 (1/16)
51 – 150	3.2 (1/8)	6.4 (1/4)
151 – 300	6.4 (1/4)	9.5 (3/8)
301 – 660	9.5 (3/8)	12.7 (1/2)
661 – 1000	19.1 (3/4)	19.1 (3/4)
^a The spacings in this table are suitable between live parts and conductive non-current carrying parts separated by basic insulation only or between basically insulated conductive non-current carrying parts and accessible parts separated by supplemental insulation. Spacings between hazardous voltage parts and accessible parts requiring double or reinforced insulation will require that the values outlined in the table be doubled. Refer to Section 5.6 regarding required insulation levels. ^b Spacings at these voltages may be decreased from those indicated in the table if it can be determined through test or analysis that there is no hazard.		

5.5.3 Conductors of circuits operating at different potentials shall be reliably separated from each other unless they are each provided with insulation acceptable for the highest potential involved.

5.5.4 An insulated conductor shall be reliably retained so that it cannot contact an uninsulated live part of a circuit operating at a different potential. Some examples include clamping or routing of conductors, use of separating barriers of insulating material or other means that provides permanent separation of the parts.

5.5.5 There are no minimum spacings applicable to parts where insulating compound completely fills the casing of a compound or subassembly if the distance through the insulation, at voltages above SELV levels is a minimum of 0.4-mm (0.02-in) thick for supplementary or reinforced insulation, and passes the Dielectric Voltage Withstand Test. There is no minimum insulation thickness requirement for insulation of circuits at or below SELV levels for basic or functional insulation. Some examples include potting, encapsulation, and vacuum impregnation.

5.6 Insulation levels and protective grounding and bonding

5.6.1 Hazardous voltage circuits shall be insulated from accessible conductive parts and circuits as outlined in 5.6.2 through the following:

- a) Basic insulation and provided with a protective grounding system for protection in the event of a fault of the basic insulation; or
- b) A system of double or reinforced insulation; or
- c) A combination of (a) and (b).

5.6.2 Safety extra low voltage (SELV) circuits (i.e. circuits at or below 60 Vdc or 42.4 V peak under normal and single fault conditions) that are insulated from accessible conductive parts through functional insulation only are considered accessible.

5.6.3 Article 250, Section VIII of the National Electrical Code, ANSI/NFPA 70 outlines dc system grounding requirements including identifying types of dc circuits and systems that must be grounded. Batteries that rely upon protective grounding, shall comply with 5.6.4 through 5.6.7.

5.6.4 Accessible non-current carrying metal parts of a electric energy storage system with hazardous voltage circuits, that could become live in the event of an insulation fault, shall be bonded to the equipment ground terminal.

5.6.5 Parts of the protective grounding system shall be reliably secured in accordance with 5.4.1.2 and provided with good metal-to-metal contact. The resistance between the protective conductive terminal of 5.6.6 and the accessible non-current carrying conductive parts outlined in 5.6.2 shall not exceed 0.1 Ω .

5.6.6 The main ground terminal of the protective grounding system shall be identified by one of the following:

- a) A green-colored, not readily removable terminal screw with a hexagonal head;
- b) A green-colored, hexagonal, not readily removable terminal nut;
- c) A green colored pressure wire connector; or
- d) The word "Ground" or the letters "G" or "GR" or the grounding symbol (IEC 60417, No. 5019) or otherwise identified by a distinctive green color.

5.6.7 Conductors, relied upon for the protective grounding and bonding system, shall be sized to handle intended fault currents and if insulated, the insulation shall be green or green and yellow striped in color. Grounding conductors are to be sized in accordance with Article 250.166 of the National Electric Code, ANSI/NFPA 70.

5.7 System safety analysis

5.7 effective February 15, 2016

5.7.1 An analysis of potential hazards (including an FMEA) shall be conducted on the device under test to determine that events that could lead to a hazardous condition have been identified and addressed through design or other means.

5.7.2 Documents that can be used as guidance for the safety analysis include:

- a) The Standard for Analysis Techniques for System Reliability – Procedure for Failure Mode and Effects Analysis (FMEA), IEC 60812;
- b) The Standard for Fault Tree Analysis (FTA), IEC 61025;
- c) The Procedures for Performing a Failure Mode, Effects, and Criticality Analysis, MIL-STD-1629A; and
- d) The Standard for Functional Safety of Electrical/Electronic/Programmable Electronic Safety Related Systems, IEC 61508, all parts.

5.7.3 The analysis of 5.7.1 is utilized to identify anticipated faults in the system which could lead to a hazardous condition and the types and levels of protection provided to mitigate the anticipated faults. The analysis shall consider single fault conditions in the protection circuit/scheme as part of the anticipated faults.

5.7.4 When conducting the analysis of 5.7.1, active protective devices shall not be relied upon for critical safety unless they comply with the following in (a) – (c). Refer to 4.35 and 4.36 for definitions of active and passive protective devices.

- a) They are provided with a redundant passive protective device; or
- b) They are provided with redundant active protection that remains functional and energized upon loss of power/failure of the first level active protection; or
- c) They are determined to fail safe upon loss of power to the active circuit.

5.7.5 Devices relied upon for critical safety as noted in 5.7.4 shall be tested for functionality in accordance with appropriate functional safety requirements unless already evaluated through the other tests of this standard.

5.7.6 The safety system analysis for those EESSs that are identified as smart grid enabled, smart grid compatible or smart grid interactive as defined in 1.1 of the Outline of Investigation for Safety Products in Smart Environments, UL 2744, shall include analysis of impact to safety as a result of integration of the EESS in a smart environment.