Energy Storage NEWS WEBINAR

IHI terrasun SOLUTIONS

What experts think you should know about UL9540 codes and standards for battery storage

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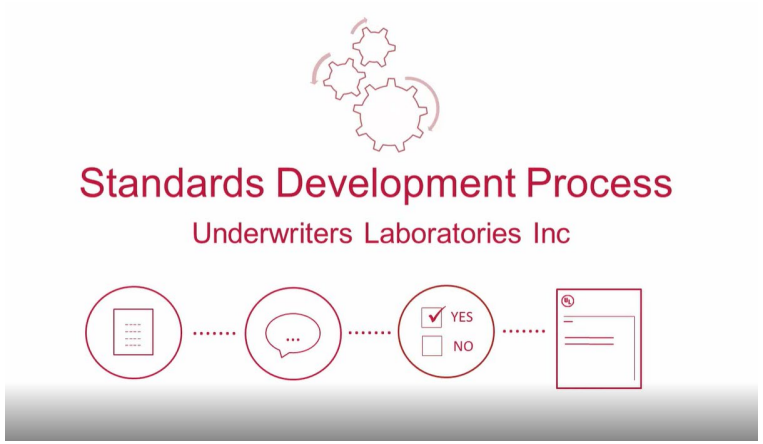
In this section

- Introduction to UL 9540
- Integrator's approach to using UL 9540 codes
- Documenting everything required to meet the codes
- Interface with local Authority Having Jurisdiction (AHJ)

What is UL 9540?



UL Standards Development Process Video

- UL 9540 is a required safety listing / certification that battery energy storage systems (BESS) need for operation
- A Standards Technical Panel (STP) consists of 124 voting members from the energy storage industry
  - Steve Douglas and I are members of the STP. Members are from OEMs, testing labs, integrators, utilities, etc.
- Proposals are made from the members to make the standard better and provide industry-wide safety improvements
- The 3rd Edition of UL9540 may be issued in 2023

What is UL 9540?

- The process ensures BESS meet major industry code requirements
  - NFPA 70 - National Electric Code
  - NFPA 855 - Standard for the Installation of Stationary Energy Storage Systems
  - International Fire Code
- The scope of UL 9540 can be limited to the battery cabinet/container or include the inverters and/or DC converters

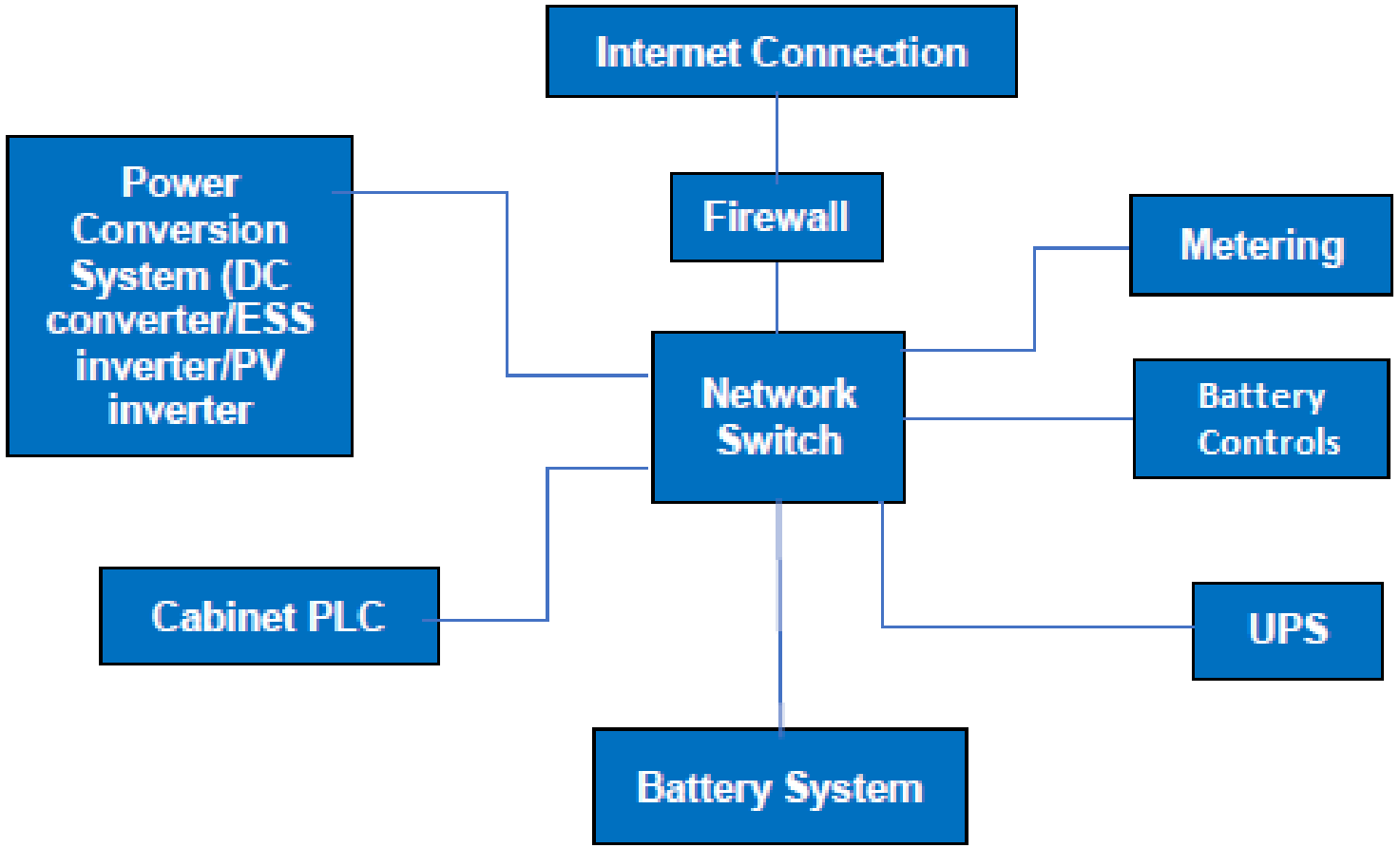
Integrator's approach to UL 9540

- Create the following UL 9540 and NFPA 855 required documents
  - Safety Analysis
  - Hazard Mitigation Analysis (HMA)
  - Failure Modes and Effects Analysis (FMEA)
- MIL-STD-1629A is used to perform FMEA
- Document control system (EMS) functions and features
- Document all sub-component marks of conformity (UL, CSA, etc. listings)
- Document all critical failure modes and causes

Integrator's approach to UL 9540

A detailed description of each component is required.

Control System Architecture



Integrator's approach to UL 9540

Where sub-components do not have listings, field evaluations can be performed.

Sub-component Documentation (UL, CSA, etc. listings) Example

Item no.	Name	Manufacturer/ trademark	Type / model	System	Mark(s) of conformity
2	Fire Suppression System	Fike	FM-200 or Novak-1230	ESS Cabinet System	UL
3	Inverter/ Converter	See Table 3.4-b	Various	Power Conversion System	UL1741, CSA C22.2 No. 107.1
4	DC disconnect	ABB	T7D/PV-E-1600	ESS Cabinet System	Tested by QPS See Note*
5	DC Disconnect Fuse	Littelfuse	P5X1XLFL0630 P5X3XLFL0700 P5X3XLFL0900	ESS Cabinet System	UL 248-13 Recognized, cURus

Integrator's approach to UL 9540

- Category I or II severity classification items are listed separately from the main FMEA analysis.
- Category I – Catastrophic – A failure which may cause death.
- Category II – Critical – A failure which may cause severe injury and/or major property damage.

Critical Failure Modes

Category 1 or 2 Failure Mode and Cause	Failure Effect	Failure Detection/Mitigation	Critical Safety Components
Battery Overcharge (BMS/Control Box failure)	Thermal runaway, Fire, Equipment Damage or Loss	Fire suppression system smoke detector will detect smoke. Off-Gas detection system will detect battery off gas. Control System will shutdown Battery System operation.	BMS/Control Box
Short Circuit (inside enclosure – non-battery related)	Fire, Arcing, Equipment Damage or Loss	Fire suppression system smoke detector will detect smoke and suppress the fire within the enclosure	See below
DC/DC Converter Internal Short Circuit	Fire, Arcing, Equipment Damage or Loss	DC/DC Converter internal overcurrent detection and protection	DC/DC Converter
DC/DC Converter Internal Control Failure	Equipment Damage or Loss	Control Box Overcurrent/Overvoltage Trip	DC/DC Converter and Control Box

Integrator's approach to UL 9540

The following circuit paths are evaluated for a fault and the critical component to open the circuit is noted (thus identifying it as a "critical component").

Short Circuit Path & Protective Device

Circuit Path From	Circuit Path To	Short Circuit Protective Device (Critical Component)	Notes
Battery Rack	DC Disconnect	Control box protection (DC Fuse)	*Circuit protection for each Battery Rack contained in battery control box (UL Listed), typical for each rack
DC bus	DC/DC Converter	DC Disconnect DC Fuse	
DC Converter	PV Inverter	DC Fuses at inverter	
HVAC Units	AC Panel	MCCB	Typical for HVAC units
Fire Suppression Control Panel	AC Panel	MCCB	
UPS	AC Panel	MCCB	Via receptacle
Receptacles	AC Panel	MCCB	
N/A	AC Panel	MCCB	Panel A Main CB, bus fault
Battery Racks	AC Panel	MCCB	

Integrator's approach to UL 9540

FMEA Worksheet Examples for Various BESS components

ID	Item / Functional Identification	Function	Failure Mode	Failure Cause (Note 1)	Mission Phase/ Operational Mode	Failure Effects (Note 2)	Failure Detection Method	Compensating Provisions	Severity Class	Remarks
A.1.1	Battery System	See Section 2.3	System BMS Fault (MBMU)	Hardware/software/com failure	Normal Operation	System shutdown	ES Pilot	Function check (pre-shipment & after delivery)	III	Fault state
A.2.1	Power Conversion System	See Section 2.3	Internal Control Failure	Hardware/Software or Communication failure	Normal Operation	Converter fuse blown, Converter Shutdown, Control Box Overcurrent/Overvoltage Trip	Operator, System Shutdown	Control Box opens MC.	II	
A.3.1	Controls System	See Section 2.3	Internet failure, failure of cellular modem/service	ISP failure, Int hardware failure	Normal Operation	Loss of Remote Monitoring & Diagnostics (RM&D), control (last command active)	Operator, System Shutdown	Use of well-tested or certified equipment	IV	
A.4.1	ESS Cabinet – Aux Power	See Section 2.3	Loss of AC station aux power	Grid loss, transformer failure, AC power equipment failure	Normal Operation	BESS Shutdown, HVAC system shutdown, FSS system shutdown (after battery backup is depleted)	Operator, System Shutdown	UPS provided for short term backup for system shutdown.	III	FSS system provided with battery backup.

Recent industry code updates

NFPA 855 changes on explosion control

- Battery cabinets shall meet NFPA 68 (deflagration venting) **or** NFPA 69 (explosion prevention venting)
- If complying to NFPA 69, the gas detection system shall be provided with 24 hours of standby power and 2 hours in alarm
- Actual test results and/or CFD analysis is expected to be required to show compliance to NFPA 68 or NFPA 69
- Smoke and fire detection systems shall also be provided with 24 hours of standby power and 2 hours in alarm, in accordance with NFPA 72

Considerations for each project

Has the battery system completed a code compliance review?

- Battery OEMs have new product nearly every 2 years
- Thorough reviews of new products are required to ensure permit approval of new battery systems
- In North America, Authority Having Jurisdictions (AHJ) act as the enforcement arm of the NFPA 855 and NFPA 68 / 69 requirements

Carrie Kaplan,
Energy Storage Safety Team Lead, DNV

Mark Kellenberger,
Senior Engineer, Energy Storage Safety, DNV

In this section

- Large-scale fire testing: UL 9540A
  - Intention of the test
  - Typical test data
  - How can it be used
- Fire suppression systems
- Explosion controls

Intentions of UL 9540A

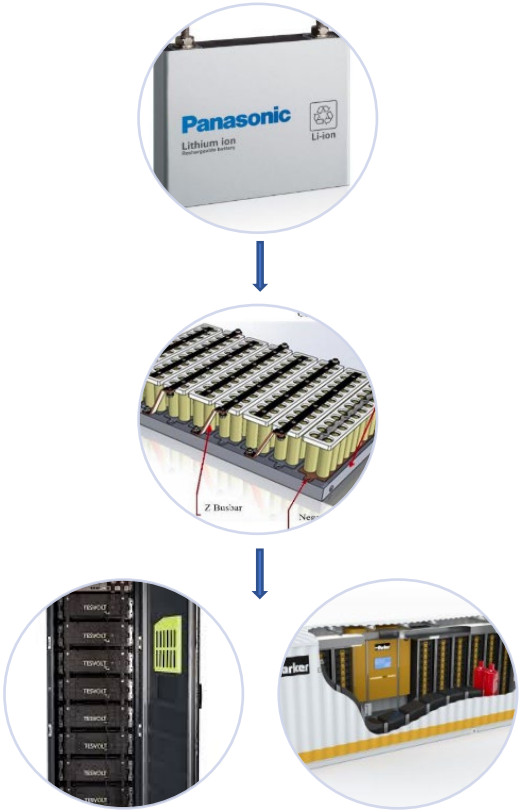
- Overall
  - Determines capability to undergo thermal runaway*
  - Evaluates fire and explosion hazard characteristics

*All lithium-ion batteries currently on the market can undergo thermal runaway.

- When is testing required?
  - Both NFPA 855: 2023 and IFC 2021 require UL 9540A or equivalent testing.
    - Large scale fire testing is required for most installations

Underwriters Laboratories Inc., *ANSI/CAN/UL 9450A, Standard for Safety for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*, 2019.

Intentions of UL 9540A



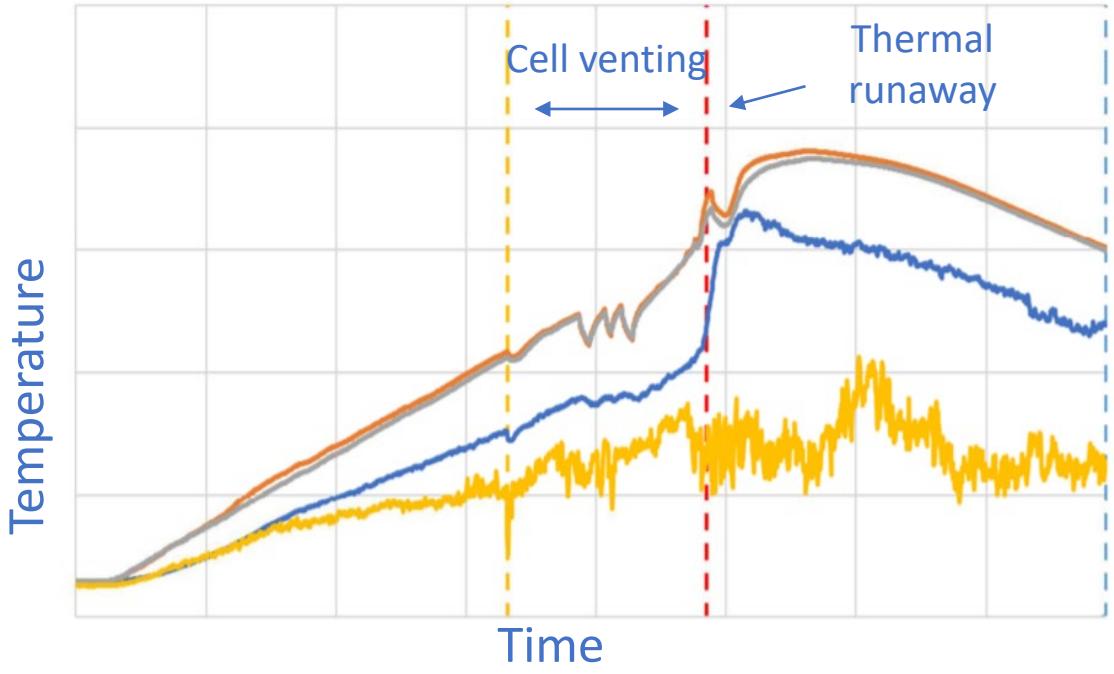
4 levels of testing

- Cell level
  - Can the cell undergo thermal runaway? Are the vent gases flammable?
- Module level
  - Is thermal runaway contained by the module design? Are the vent gases flammable?
- Unit level
  - Does the heat generated affect surrounding exposures? Is there an explosion hazard? Is there a fire hazard?
- Installation level*
  - Are the fire and explosion mitigations effective?

*Typically, lithium-ion based BESS don't reach this level

Underwriters Laboratories Inc., *ANSI/CAN/UL 9450A, Standard for Safety for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems,* 2019.

Typical test data



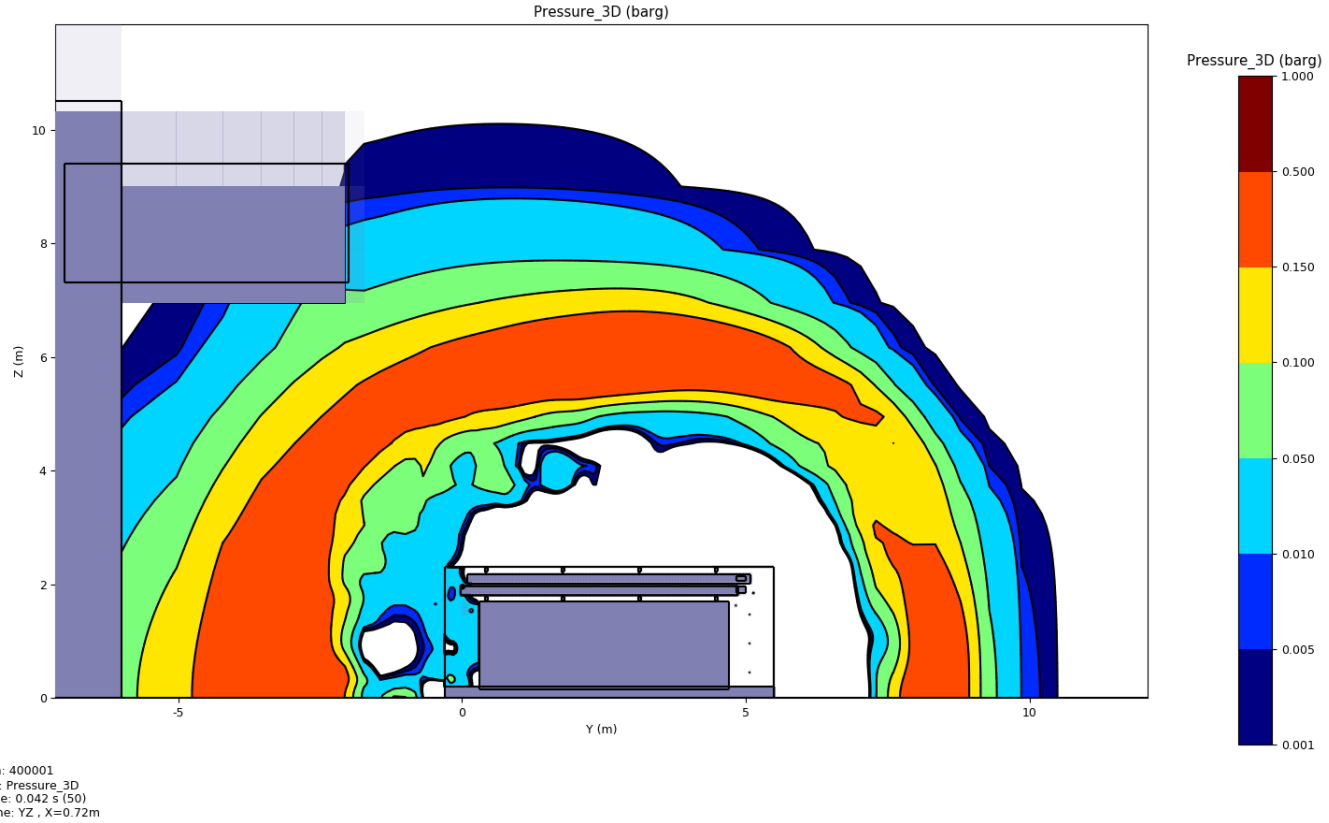
Note: colored lines indicate different thermocouples.

Important data considerations

- Cell level
  - Venting and thermal runaway temperatures
  - Off-gas volume and composition
- Module level
  - Level of thermal runaway propagation between cells*
  - Flammability of off-gas
- Unit level
  - Effect of thermal runaway on adjacent exposures (target BESS, walls, means of egress)

*4th edition requires cell-to-cell propagation

Typical test data



Run: 400001
Var: Pressure_3D
Time: 0.042 s (50)
Plane: YZ , X=0.72m

Potential uses for data

- Cell level
  - BMS monitoring/alarm considerations
  - Flammability and toxicity of the vented gases
- Module level
  - Explosion control considerations
- Unit level
  - Minimum spacing requirements between units, means of egress, and walls
  - Fire suppression considerations
  - Used to validate inherent fire safety features

Fire safety features

- Safety features requirements vary based on project size and location
- Typical requirements may include:
  - BMS monitoring cell or multiple cell temperatures
  - Smoke and heat detectors
  - Fire alarm (visual & audible) with links to remote monitoring
  - Emergency stop buttons linked to site circuit breakers
  - Fire suppression system

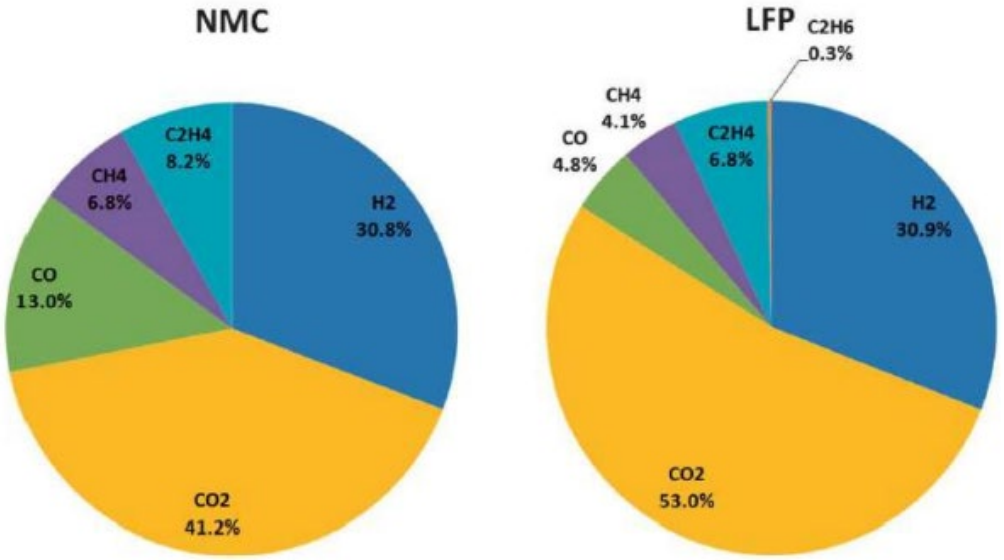
Fire detection and suppression

- Most common*:
  - Clean Agent gas – Novec, FM200
  - Aerosol - Stat-X
  - Water based – sprinkler or dry risers

*Active area of improvement by industry and first responders

- Two fire fighting philosophies:
  - Active engagement
  - “Let it burn”

Explosion prevention and protection



Courtesy of Amphenol Sensors

- Explosion prevention
  - Ventilation system
  - NFPA 69, Standard on Explosion Prevention Systems
- Explosion protection
  - Deflagration venting panels
  - NFPA 68, Standard on Explosion Protection by Deflagration
- Gas detection
  - Added layer of prevention

All use UL 9540A to inform design

Steve Douglas

Senior Technical Codes Specialist,

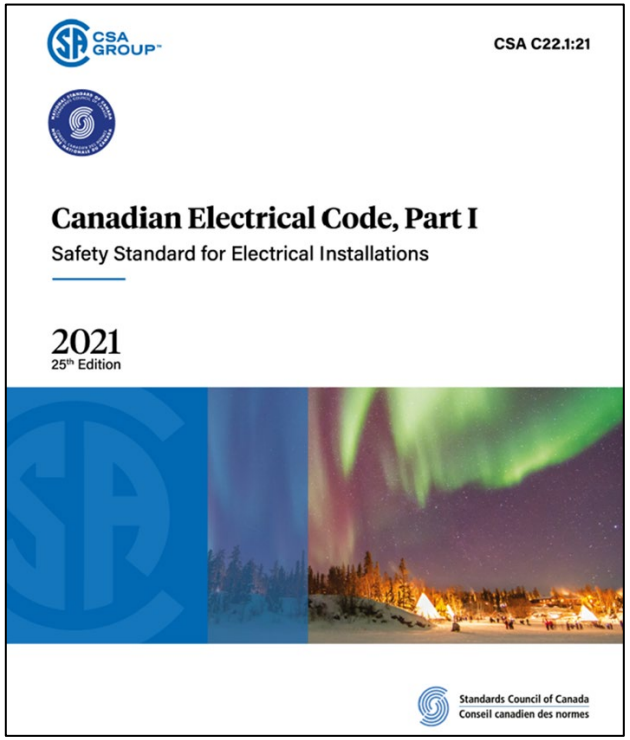
QPS Evaluation Services

In this section

- Approval / Listing and Labelling
- Standards
- Project Review
- Field Evaluation
- AHJ Involvement

Approval Listing and Labeling

Canadian Electrical Code (CE Code) Rule 2-024



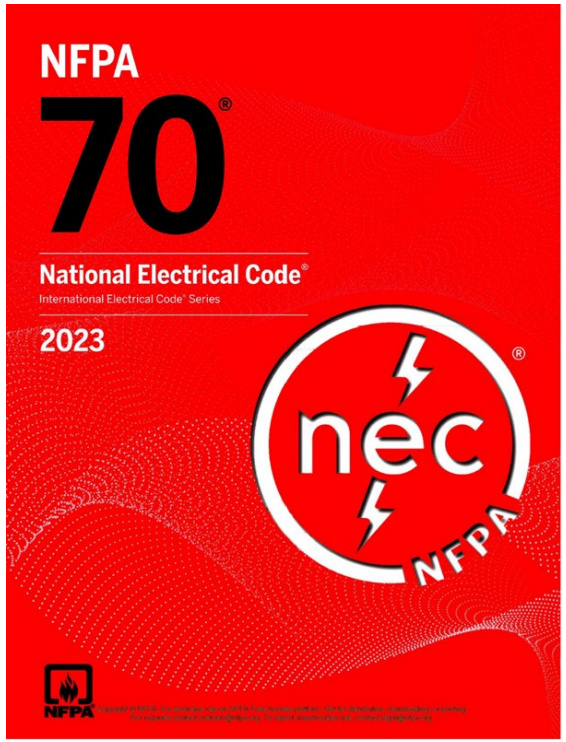
2-024 Use of approved equipment (see Appendix B)

1) Electrical equipment used in electrical installations within the jurisdiction of the inspection department shall be approved and shall be of a kind or type and rating approved for the specific purpose for which it is to be employed.

2) Notwithstanding Subrule 1), equipment described in Rule 16-222 1) a) shall not be required to be approved.

Approval Listing and Labeling

National Electrical Code (NEC) Article 110.2



110.2 Approval

The conductors and equipment required or permitted by this Code shall be acceptable only if approved.

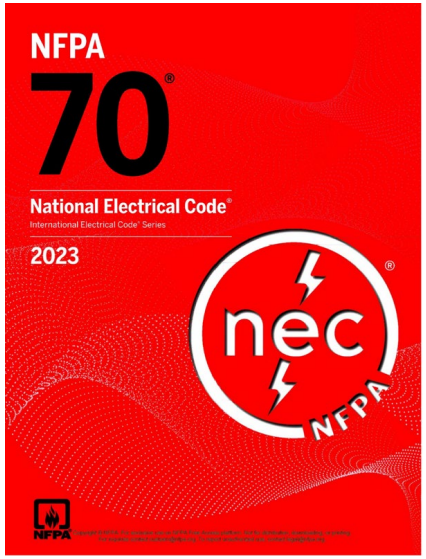
Informational Note: See 90.7, Examination of Equipment for Safety, and 110.3, Examination, Identification, Installation, and Use of Equipment. See definitions of Approved, Identified, Labeled, and Listed.

Approved.

Acceptable to the authority having jurisdiction.

Approval Listing and Labeling

National Electrical Code (NEC) Article 110.2



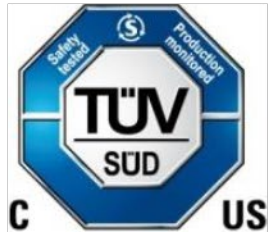
Listed.

Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.

Labeled.

Equipment or materials to which has been attached a label, symbol, or other identifying mark of an organization that is acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of labeled equipment or materials, and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.

Acceptable Full Certification Markings



Acceptable Component Recognition Markings

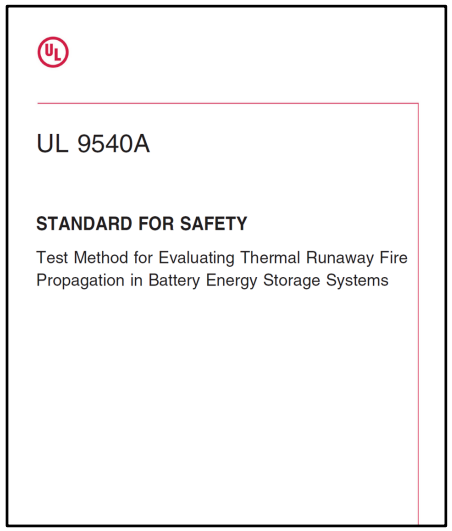
Acceptable Component Recognition Markings

Conditions of Acceptability

Standards

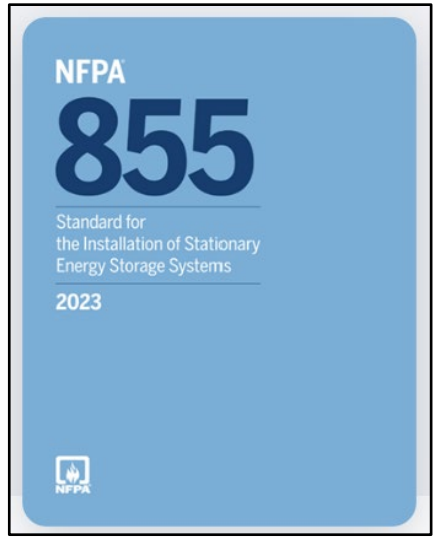
UL 9540

UL 9540A



UL 1973

NFPA 855

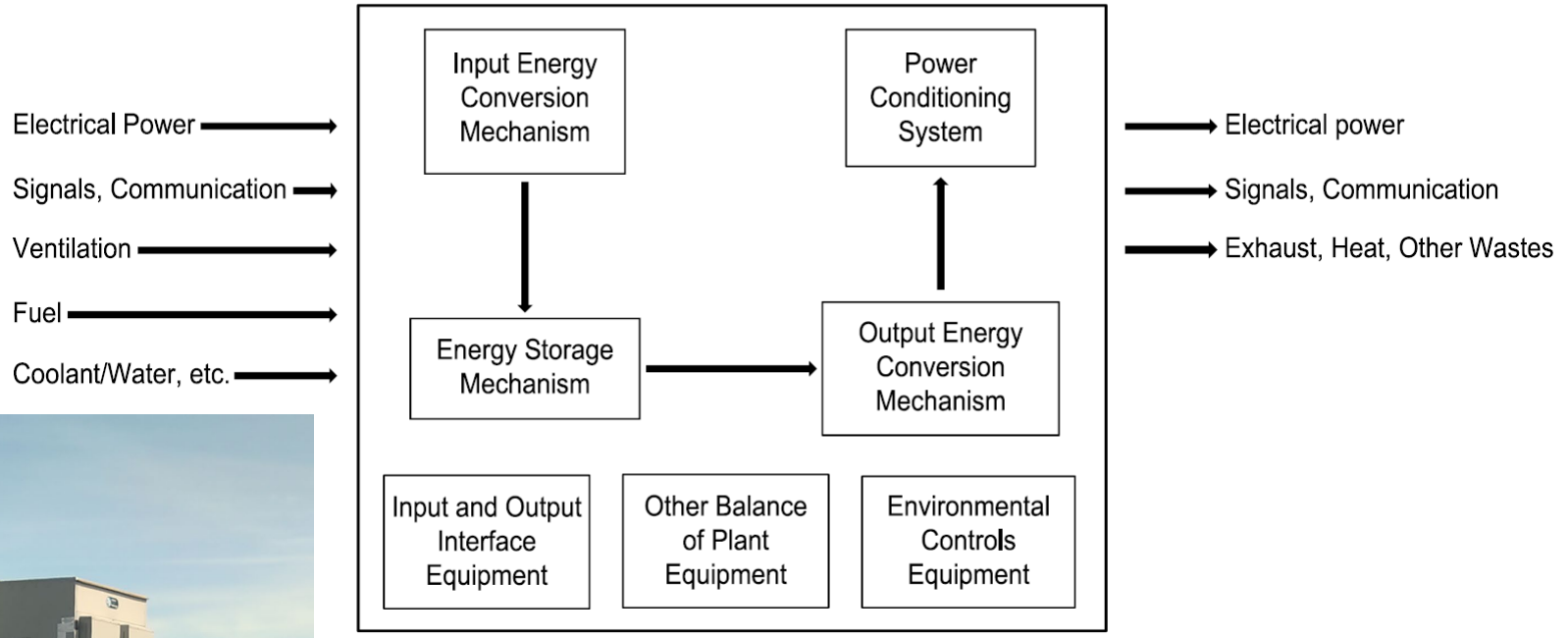


Standards

UL 9540

Figure 6.1

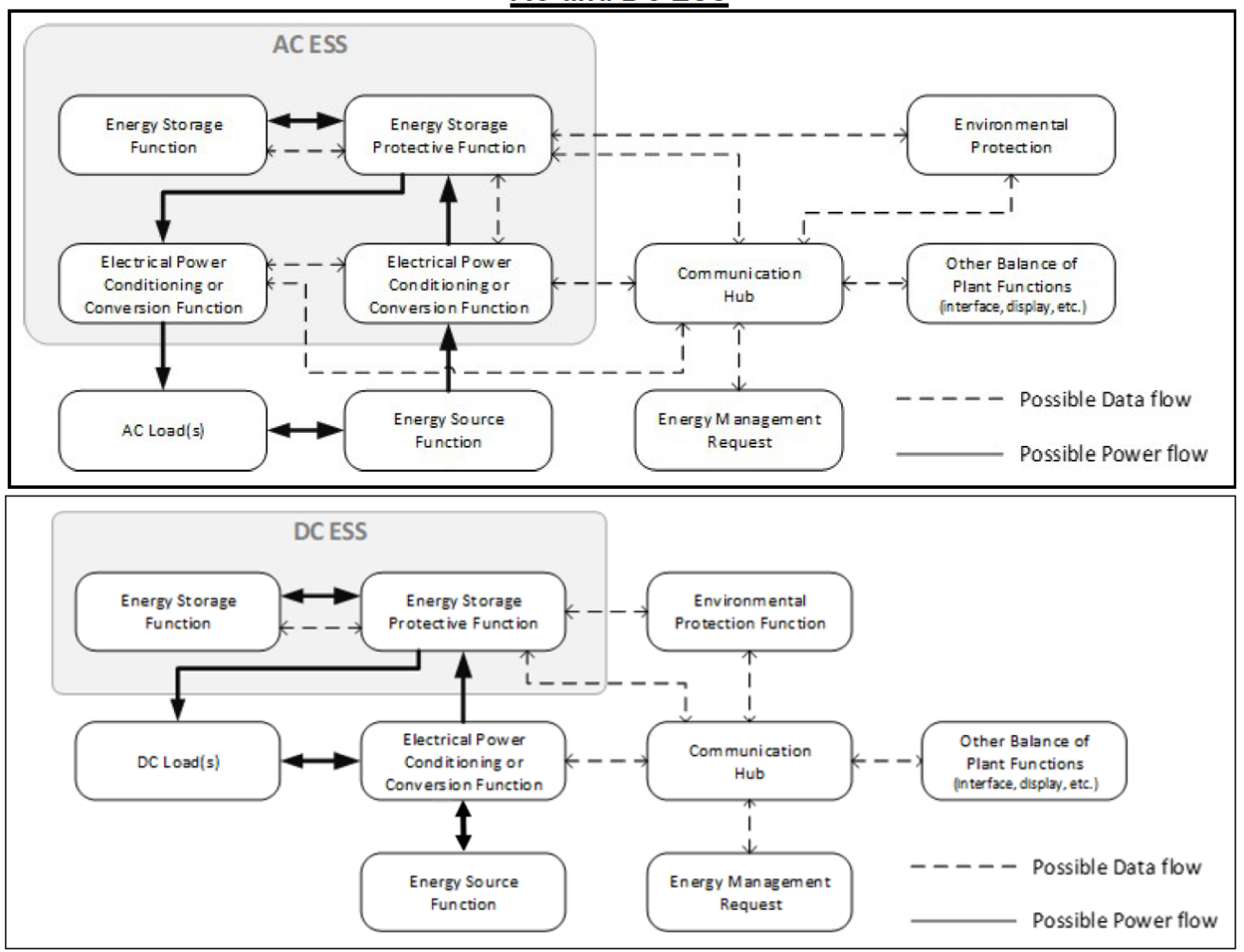
Block Diagram of Energy Storage System



Standards

UL 9540
Proposed Figure 6.1

Figure 6.1
AC and DC ESS



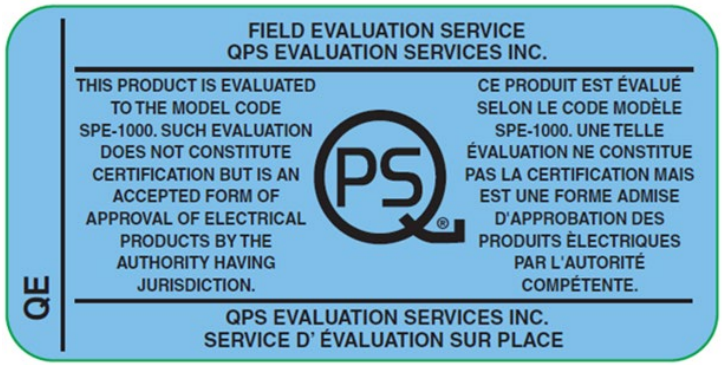
UL9540 Project Review

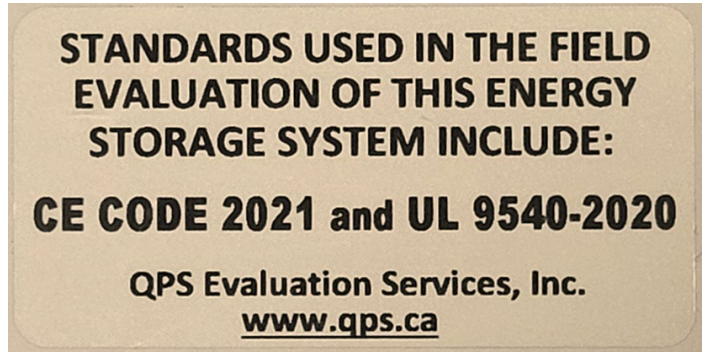
1. Safety Analysis
2. Fire Risk Analysis
3. Arc Flash Analysis
4. Critical Component System Analysis

UL9540 Project Review

5. Installation, commissioning, operation and maintenance Instructions (cont'd)
    a. Procedures for system commissioning and decommissioning;
    b. Complete installation instructions,
    c. Initial acceptance testing procedures;
    d. Ongoing inspection and testing procedures;
    e. Instructions for retrofitting system components
    f. Instruction for providing working clearances
    g. Minimum separation distances
    h. Additional fire suppression and/or fire protection identified in the UL 9540A test report

Field Evaluation Labels





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