EASE Guidelines on Safety Best Practices for Battery Energy Storage Systems

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European Association for Storage of Energy

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Preface

The EASE Guidelines on Safety Best Practices for Battery Energy Storage Systems (BESS) are designed to support the safe deployment of outdoor, utility-scale lithium-ion (Li-ion) BESS across Europe. These guidelines aim to assist developers, manufacturers, service providers, and all stakeholders in the value chain—including relevant authorities, first responders, and permitting bodies—in implementing safety practices that align with regulatory requirements and technical standards.

The document is structured as follows:

- Chapter 1 outlines the scope, definitions, and EU regulatory context, with a focus on the Batteries Regulation (2023/1542).
- Chapter 2 covers product safety, including design, management systems, thermal control, fire detection, and explosion prevention.
- Chapter 3 details site safety, including location, security, container spacing, liquid containment, and fire safety.
- Chapter 4 focuses on personnel safety, including response plans, training, PPE, and maintenance.
- The Annex provides technical references, and relevant standards.

Table of Contents

1. Introduction

This paper provides guidance on best practices for lithium-ion BESS safety, targeted at developers, manufacturers, and relevant authorities across Europe, including fire services. It aims to support informed decision-making on safety measures.

As the European Union strives for climate neutrality by 2050, the need for safe and reliable energy storage has grown significantly. In 2024, Europe presented 35 GW of cumulative installed capacity of electrochemical storage, reflecting the rapid expansion of BESS and their crucial role in the global energy transition. Ensuring these systems meet the highest safety standards in design, development, installation, and maintenance is essential to support this growth.

The Batteries Regulation (Regulation (EU) 2023/1542) requires that stationary BESS be safe during normal operation and use. It mandates demonstration of compliance with state-of-the-art testing methods developed by organisations such as the European Committee for Electrotechnical Standardisation (CENELEC) and the International Electrotechnical Commission (IEC) and other organisations with global recognition.

In response to these requirements, this document outlines safety guidelines specifically for outdoor, utility-scale lithium-ion BESS. It does not address other types of batteries (i.e. as redox flow batteries) which have distinct risk profiles. The focus is on systems with a maximum DC voltage of 1500 V or a maximum AC voltage of 1000 V and an energy storage capacity exceeding 20 kWh.

While not exhaustive, this guide highlights recognised industry best practices for demonstrating safety compliance, focusing on Product Safety (Chapter 2), Site Safety (Chapter 3), and Personnel Safety (Chapter 4).

Given the rapid evolution of the BESS industry and its associated regulations, codes and standards, this document is intended to serve as a living resource, subject to updates as new developments emerge.

Version: May 2025

1.1. List of Abbreviations

BESS – Battery Energy Storage System

BOS – Balance of System

BMS – Battery Management System

CENELEC – European Committee for Electrotechnical Standardisation

CCTV – Closed-Circuit Television

DC – Direct Current

EPRI – Electric Power Research Institute

EU – European Union

HVAC – Heating, Ventilation, and Air Conditioning

IEC – International Electrotechnical Commission

IP – Ingress Protection

NFPA – National Fire Protection Association

PCS – Power Conversion System

PPE – Personal Protective Equipment

TFEU – Treaty on the Functioning of the European Union

UL – Underwriters Laboratories

UPS – Uninterruptible Power Supply

1.2. Technology Overview: Lithium-ion Battery Energy Storage Systems

A BESS, as defined by IEC 62933-1, consists of several subsystems: the accumulation subsystem, power conversion subsystem, auxiliary subsystem, control subsystem, and connection terminal. The safety of the accumulation subsystem, particularly for electrochemical batteries like Li-ion,[1] is addressed in Chapter 2, which focuses on product safety. Chapter 3, covering site safety, encompasses the entire BESS, including all subsystems and civil components.

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[1] EASE. Energy Storage Technologies. Available at: https://ease-storage.eu/energy-storage/technologies/. Accessed: 2024.

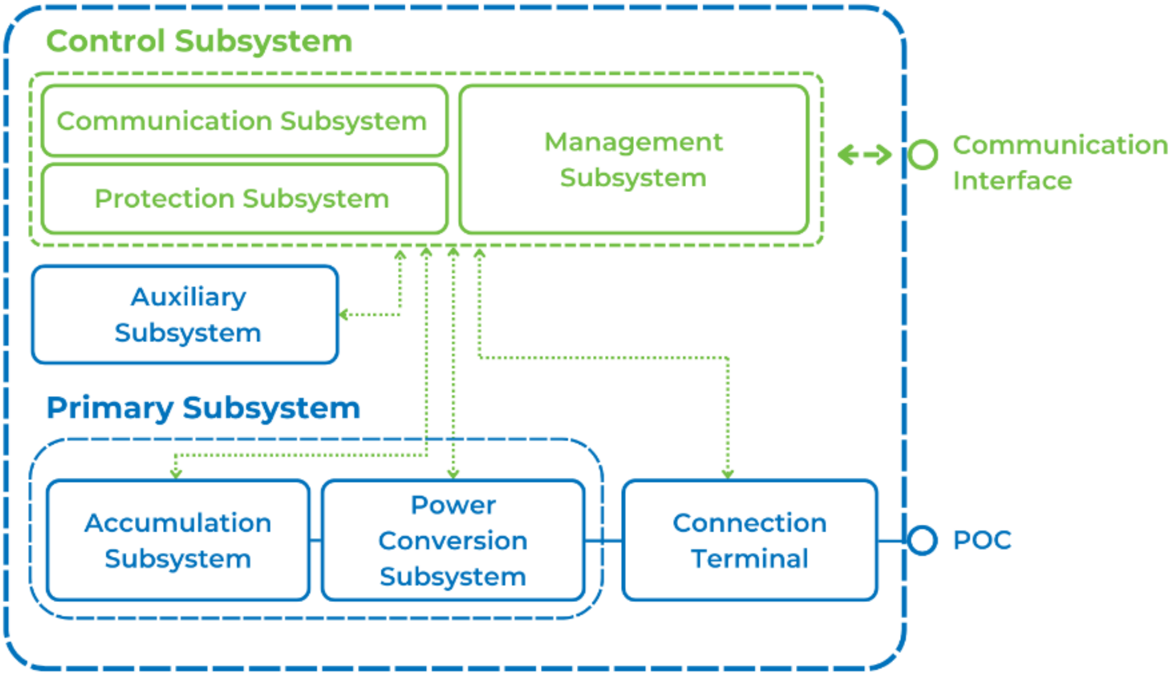

Figure 1: One of BESS architectures according to IEC 62933-1:2024, Electrical energy storage (EES) systems - Part 1: Vocabulary

1.3. Battery Energy Storage Systems Applications

Due to their high scalability in energy capacity and flexibility in power delivery, Li-ion batteries are used in a large variety of applications, addressing the needs of various sectors in the energy landscape:

- **Behind the Meter (BtM) Residential (R-BESS) and commercial/industrial (C&I-BESS)**: PV self-consumption, peak shaving, atypical grid usage.
- **Front of the Meter (FTM) District (D-BESS):** Local utilisation of local renewable energy sources (energy communities), local energy trading, combination with EV charging, grid services.
- **FTM Utility-scale stand-alone (U-BESS) BESS**: Ancillary services (e.g. inertia and reactive power), Frequency Containment Reserve (FCR) and Automatic Frequency Restoration Reserves (aFRR), arbitrage.
- **FTM co-location BESS with PV and/or wind (Co-BESS):** Participation in energy markets (controlled feeding-in, arbitrage), in power markets (FCR and aFFR) as well as provision of ancillary services (e.g. inertia and reactive power).

1.4. Overview of Failures

This guideline addresses product, site, and personnel safety, focusing on utility-scale outdoor BESS installations. For this, it is helpful to analyse BESS field failures to be able give recommendations on how to improve BESS safety.

The Electric Power Research Institute (EPRI)[2] conducted an in-depth analysis of BESS failures using data from its BESS Failure Incident Database. The study highlights both developments in safety and ongoing challenges in the rapidly expanding BESS sector. It categorises failures by their root causes, design, manufacturing, integration, and operation, and identifies the specific components responsible for failures, including battery cells, control systems, and balance of system (BOS) components. As per the analysis, the root causes of these failures are further described in the following table:

Root cause	Description
Design	Flaws in system architecture, component layout, or lack of safeguards.
Manufacturing	Defects in the production process, such as foreign materials or assembly errors.
Integration, Assembly, and Construction	Poor integration, incompatible components, or inadequate commissioning.
Operation	Exceeding design limits or incorrect parameter sensing (e.g., temperature, voltage).

EPRI's analysis revealed that while global utility-scale BESS deployment has surged in recent years, failure rates have decreased significantly, dropping by 97% between 2018 and 2023, due to lessons learned, advancements in codes and standards, and industry efforts.[3] Most failures occurred during the early lifecycle stages, such as construction, commissioning, or the initial two years of operation.

The primary root causes of failures were identified as integration, assembly, and construction issues, with BOS components like heating ventilation and air conditioning (HVAC) systems, fire suppression mechanisms, and electrical wiring being especially vulnerable. Operational issues, primarily related to control systems exceeding safe operational limits, were the second most common cause. Contrary to popular belief, battery cells and modules were rarely the initial failing component.

EPRI proposed several strategies to address these challenges:

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[2] Electric Power Research Institute (EPRI). *Insights from Battery Energy Storage Systems (BESS) Failure Incident Database: Analysis of Failure Root Cause.* Available at: https://www.epri.com/research/products/000000003002030360. Accessed: 2024.

[3] Electric Power Research Institute (EPRI). Insights from Battery Energy Storage Systems (BESS) Failure Incident Database. EPRI, Palo Alto, CA: 2024. Report No. 3002030360.

- **Design Improvements**: Ensure compliance with international standards and guidelines and conduct site-specific hazard assessments.
- **Construction Quality Assurance**: Strengthen workforce training, implement rigorous quality checks, and enhance integration of system components.
- **Operational Enhancements**: Deploy advanced battery management systems (BMS) and predictive analytics for early anomaly detection and risk management.
- **Manufacturing Quality Control**: Increase supplier quality verification, perform factory acceptance testing, and adopt stringent manufacturing standards.

With detailed root causes identified in fewer than one-third of known incidents, these statistics must be interpreted with caution.[4] Addressing gaps in transparency and incident reporting is essential, as greater data sharing and collaboration are critical for enhancing future safety measures. The industry's success will depend on continuous improvements in standards, safety protocols, and research to mitigate risks throughout the entire BESS lifecycle.

1.5. Overview of Measures

The table below summarises safety measures for BESS, categorised into preventive, containment, and mitigation actions. It details the key systems and procedures necessary for safe operation, from design to emergency response. Each measure is cross-referenced with its corresponding section and page for ease of access.

Type of measure	Safety Requirement
Preventive	Battery Desing (section 2.1., page 12)
	Battery Management System (section 2.2., page 14)
	Thermal Management System (section 2.3., page 15)
	BESS Enclosure Design (section 2.4., page 17)
	Hazard Mitigation Analysis (section 2.5., page 19)
	Large Scale Fire Testing (section 2.10., 28)
Containment	Fire Detection and Alarm (section 2.6., page 20)
	F-Stop Mechanism and Other Shut-Down Mechanisms (section 2.7., page 21)
	Explosion Control (section 2.8., page 22)
Mitigation	Fire Safety Strategy (section 2.9., page 26)
	Location Requirements (section 3.1., page 32)
	Fencing (section 3.2., page 33)
	Water Availability at Site (section 3.3., page 33)
	Hazardous Liquids Containment (section 3.4., page 35)
	Container Spacing (section 3.5., page 36)
	Spacing Towards Power Conversion System (section 3.6., page 37)

[4] Ibid 3.

	Spacing Towards Environment (Buildings / Fence / Vegetation) (section 3.7., page 37)
	Gas/ Smoke/ Noise Emissions (section 3.8., page 38)
	Emergency Response Plan (section 4.1., page 40)
	Training (Personnel /Firefighters) (section 4.2., page 41)
	Public Access (section 4.3., page 42)
	Control and Maintenance (section 4.4., page 43)
	Recommended Personal Protection Equipment (PPE) (section 4.5., page 43)

2. Product Safety

This chapter covers the product and functional safety of BESS, from design and installation to explosion prevention and mitigation. Particular emphasis is placed on preventing and mitigating thermal runaway and its associated hazards.

The focus is on the Direct Current (DC) side of the BESS, as illustrated in the following figure:

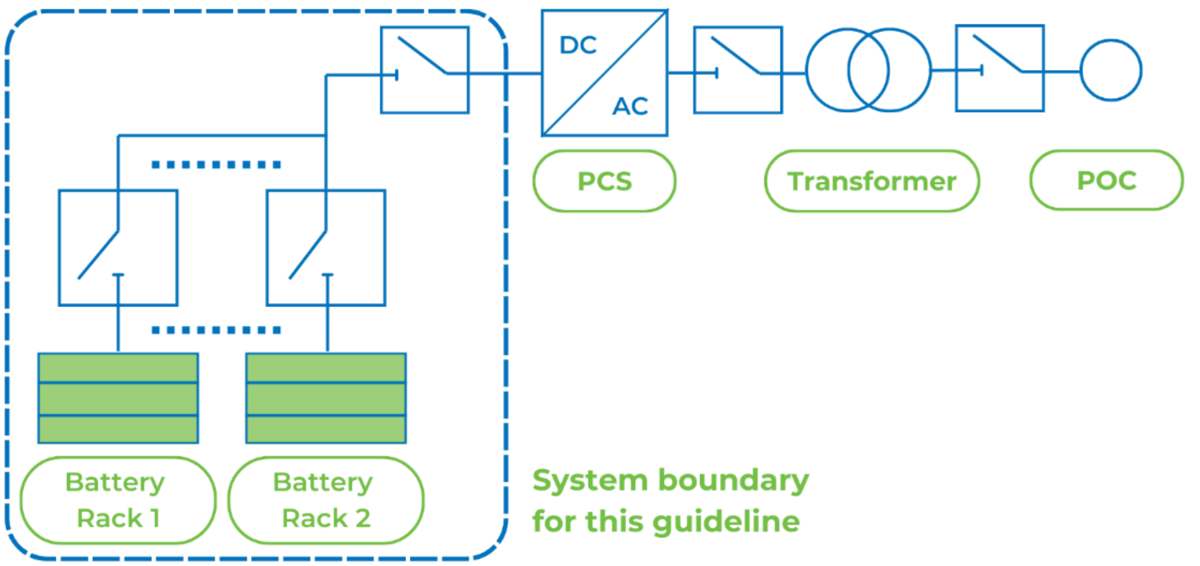

Figure 2: Adaptation of IEC 62933-5-2:2020, Electrical energy storage (EES) systems – Part 5-2: Safety requirements for grid-integrated EES systems – Electrochemical-based systems

Regarding electrical safety in the context of grid integration, national technical grid connection requirements must be considered. In particular, it is essential to ensure that:

- In the event of a high-voltage fault, no hazardous reverse currents flow into the battery, safeguarding the energy storage system;
- During high-voltage grid disturbances, the power deviation of the energy storage system remains within a specified percentage of its rated power.

Note: National and local authorities must ensure that hardware-specific product safety requirements comply with Article 34 TFEU and with the Batteries Regulation, preserving the BESS Single Market. Any such requirement must be consistent with Article 114 TFEU, and with the European Court of Justice case law.[5] Each case should be evaluated individually.

2.1. Battery Design

In the European Union, a stationary BESS must comply with Regulation (EU) 2023/1542,[6] that requires evidence that a set of minimum safety requirements are fulfilled. Additionally, it is required to conduct a risk assessment and provide evidence that the identified hazards are sufficiently mitigated.

Currently, there are no harmonised standards for this demonstration. The responsibility lies with the manufacturer to select state-of-the-art testing methodologies and declare conformity. The European Commission has requested CENELEC to develop harmonised standards, which are expected to be proposed by June 2026. Until then, manufacturers should consider a list of relevant standards for guidance (see below).

Plus, the Joint Research Centre (JRC) provides an analysis of safety tests in various international standards that could be used to show compliance with the safety parameters in the Regulation.[7] The safety parameters to be assessed are:

1) Thermal shock and cycling
2) External short circuit protection
3) Overcharge protection
4) Over-discharge protection
5) Over-temperature protection, under-temperature protection and temperature mismatch[8]
6) Thermal propagation protection
7) Mechanical damage by external forces
8) Internal short circuit
9) Thermal abuse

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[5] Case C-322/88, Commission vs. Germany.

[6] Regulation (EU) 2023/1542 of the European Parliament and of the Council of 12 July 2023 concerning batteries and waste batteries, amending Directive 2008/98/EC and Regulation (EU) 2019/1020 and repealing Directive 2006/66/EC (Text with EEA relevance). Available at: https://eur-lex.europa.eu/eli/reg/2023/1542/oj/eng. Accessed: 2024.

[7] European Commission: Joint Research Centre, Hildebrand, S., Eddarir, A., and Lebedeva, N. Overview of Battery Safety Tests in Standards for Stationary Battery Energy Storage Systems. Publications Office of the European Union, 2024. DOI: https://data.europa.eu/doi/10.2760/08079.

[8] Although these requirements are not prescribed under Regulation (EU) 2023/1542, nor in the report cited in ref. 7., they are still relevant.

10) Fire test
11) Gas, electromagnetic and noise emissions.[9]

Relevant Guidelines/Standards

There are numerous national and international standards that cover the safety of BESS. However, not a single standard covers all the safety requirements mentioned in Annex V of the Batteries Regulation. Relevant standards include:

- IEC 62933-5-1/2; 62485-5
- IEC 62619; 63056
- UL 9540/A; 1973

Are They Sufficient/Exhaustive?

Numerous standards have been developed to address various BESS hazards. In the EU, some IEC standards are available, but they are not as clear or widely adopted as the UL standards in the US, which are commonly used both domestically and globally. There are significant variations across these safety standards, which can impact test results and, ultimately, what is considered safe. These differences are evident in the scope and conditions of tests, with some standards evaluating individual cells and others assessing complete systems.[10]

Test parameters—such as temperature, state of charge, test procedures, and observation periods—differ considerably, and the stringency of pass/fail criteria varies widely between standards. Additionally, many standards do not provide clear methods for verifying pass/fail criteria, leaving room for interpretation by test performers and by those authorities that must make informed decisions about installation requirements and safety measures.[11] As a result, these standards should be viewed as the minimum requirements, not the maximum. Best practices in the industry are continuously evolving, and stakeholders will stay informed on new regulations as they emerge from bodies like the EU.

EASE Recommendation

To ensure a consistent minimum level of safety for BESS worldwide and to reduce the compliance burden on stakeholders, it is recommended that international harmonisation of standards be pursued. Establishing unified global standards will facilitate the adoption of best safety practices across all regions, enhancing safety and streamlining regulatory compliance.

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[9] Although these requirements are not prescribed under Regulation (EU) 2023/1542, nor in the report cited in ref. 7., they are still relevant.

[10] Overview of battery safety tests in standards for stationary battery energy storage systems, Publications Office of the European Union, Luxembourg, 2024, doi:10.2760/08079, JRC135870.

[11] Ibid 9.

As for the sample size of thermal propagation type tests, the standards listed above shall be followed. Although not mandatory, consideration should be given to revising the sample size for thermal propagation type tests.

2.2. Battery Management System

A Battery Management System (BMS) must ensure the safety and reliability of battery systems by adhering to functional safety standards. A robust BMS should:

- Protect the battery from, at least, operation outside safe limits (voltage, current, temperature). Plus, cell balancing to ensure uniform charge distribution.
- Continuously monitor critical parameters such as voltage, current, and temperature in real-time.
- Transmit data to a management system for immediate analysis and proactive risk mitigation.
- Maintain operational continuity and/or safe shutdown, by securing the BMS power supply during safety-critical conditions.

Relevant Guidelines/Standards*

Safety parameter	Standard	Description
Functional safety compliance	IEC 62619	Active and programmable protection devices monitor and maintain cells within safe operating parameters (e.g., overvoltage, undervoltage, etc.).
	SA C22.2 No. 0.8(Function Class B requirements)	Safety functions incorporating electronic technology.
	Annex H CSA E60730-1 or 60730-1	Automatic Electrical Controls.
	UL 1973	Batteries for Use in Stationary and Motive Auxiliary Power Applications.
	UL 991	Tests for Safety-Related Controls Employing Solid-State Devices.
	UL 1998	Software in Programmable Components.
	IEC 61508	Active protective devices that comply with IEC 61508 (all parts), meeting minimum Safety Integrity Level (SIL) “2”,

	ISO 13849 ISO 26262	ISO 13849 (all parts), meeting minimum performance level (PL) "C", or ISO 26262 (all parts), minimum of Automotive Safety Integrity Level (ASIL) "C" or are permitted to be relied upon for critical safety. The SIL, PL, or ASIL for a safety function may be reduced if the manufacturer provides additional safety analysis, e.g. Layer of Protection Analysis (LOPA), showing that the required risk reduction level has been reduced by other measures used within the battery system.
BESS safety requirements	IEC 62933-5-2	EES safety requirements for grid-integrated electrochemical-based system.
Power converter safety	IEC 62019-1	Power converter safety.

** These standards are applicable to different safety approach types (non-exhaustive list provided for illustration purposes only.)*

Are They Sufficient/Exhaustive?

While the current standards provide strong safety frameworks, they are insufficient for the complex requirements of modern BESS. To completely address potential system failures, it is advised that compliance be integrated with real-world testing under different scenarios.

EASE Recommendation

To enhance BMS safety, the following should be considered when sufficient level of technology development is reached:

- Incorporate advanced diagnostic and predictive maintenance tools within the BMS.
- Ensure seamless compatibility between the BMS and other system components.
- Expand the scope of BMS testing to include large-scale operational scenarios, ensuring real-world applicability and reliability.
- Enhance the safety design of BMS to avoid fire caused by short circuit of the BMS itself.
- BMS should be functional for example by being backed up by an UPS, where possible, so that data can be monitored and used to assess the severity and development of the fault. This can give input on how to safely react to the incident. Other options remain such as real-time data upload to a cloud.

2.3. Thermal Management System

Thermal management is critical to ensuring the safety, performance, and longevity of Li-ion cells in BESS. The two primary methods used for this purpose are the following:

- **Liquid cooling** is effective at maintaining homogeneous temperatures throughout the battery modules but introduces risks which have to be mitigated by a proper pack/system design (e.g. leakage). Leaks can cause short circuits, corrosion dependent on the chosen medium, or damage to battery cells and components.[12]
- **Air cooling** avoids internal leak-related risks but may be less effective in managing heat in high-capacity systems.[13]

Relevant Guidelines/Standards

- ANSI/CAN/UL 1973:2022
- UL 9540:2025

Are They Sufficient/Exhaustive?

Current standards establish a solid baseline for thermal management. For example: Chapter 7.10 of UL 1973:2022 specifies requirements to minimise leakage risks in liquid cooling systems. It also calls out the consequences of leakage (in chapter 7.11.2) where it is prescribed that piping, hose, and tubing containing fluids or liquid (coolant), shall be routed and secured to prevent leakage.

UL 9540:2023 aligns with these principles, ensuring robust design to mitigate fire, explosion, or shock hazards.

EASE Recommendation

To improve thermal management safety, it is recommended to:

- Ensure thermal management systems are designed for optimal performance under critical conditions without relying on uninterruptible power supplies (UPS), as their high-power demand (30kW-60kW) makes continuous operation impractical. Additionally, running liquid cooling systems during failure scenarios may increase risks if leaks occur.
- Ensure leakage alarms or warnings from the Thermal Management System are communicated to the BMS without fully integrating control functions into it, as the BMS already manages multiple critical battery operations.
- Conduct comprehensive risk assessments for cooling systems and validate them through recognised certification processes.

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[12] Thermal management system regulates the temperature of the system and usually, especially liquid-based TM systems, can both cool and heat. The latter is important at low ambient temperatures. More information on battery thermal management systems can be found on page 8 of JRC Publications Repository - Detection of liquid electrolyte leakage from Li-ion batteries by signalling the presence of Li ions.

[13] Air cooled enclosures, compared to liquid cooled, are more vulnerable to water and dust ingress, due to the increase of necessary openings and air intakes.

2.4. Battery Energy Storage Systems Enclosure Design

Outdoor BESS enclosures must safeguard against hazardous parts and environmental factors. The primary risks to address are:

- Dust and solid foreign objects ingress
- Water ingress
- Mechanical impacts
- Corrosion
- Vermin
- Solar radiation
- Icing
- Moisture from condensation
- Debris or build-up around intakes or outlets.

The degree of protection is generally specified by the manufacture through IEC 60529 "Degrees of protection provided by enclosures (IP Code)". The exact degree of protection provided by the enclosure may vary based on regional regulations, the specific location of the installation, and environmental risk factors like potential flooding zone or extreme weather events. Therefore, a tailored risk assessment is recommended to determine the most suitable IP Code for the installation location. Water and solid foreign object intrusion into the BESS has been identified as root cause for fires in BESS.[14] This intrusion can compromise electrical insulation resistance which may lead to thermal runaway. [15]

BESS enclosures can also play a critical role in fire safety, serving to prevent or delay fire propagation. While prescribing a specific fire resistance classification may not always be necessary, the mitigation of fire spread must be addressed through appropriate measures.

Spatial separation, for instance, is an effective alternative to fire-resistant barriers, and should be objectively set. UL 9540 test results (or Large-Scale Fire Testing exceeding these standards), for instance, can inform spatial separation, based on a manufacturer's UL 9540A Test Report.

Another fire mitigation strategy is compartmentalisation, which involves dividing the enclosure into smaller, isolated fire cells to contain potential fires within a single compartment. However, this method is only suitable for certain BESS designs and architectures. In some alternative designs, components are intentionally packed together rather than separated into compartments, requiring a different approach to fire mitigation.

Regardless of the selected mitigation strategy, evidence of the barriers or distance suitability for the specific application is essential. This can include:

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[14] Warwick Valley Schools. Convergent Provides Root Cause of Battery System Fire at October 5 Board Meeting. Available at: https://warwickvalleyschools.com/convergent-provides-root-cause-of-battery-system-fire-at-oct-5-board-meeting/.Accessed: 19 December 2024.

[15] Na, Yong-Un, and Jae-Wook Jeon. "Unraveling the Characteristics of ESS Fires in South Korea: An In-Depth Analysis of ESS Fire Investigation Outcomes." Fire 6, no. 10 (2023): 389. https://doi.org/10.3390/fire6100389.

- **Representative fire testing**: Simulating real-world conditions to evaluate the barrier's ability to withstand thermal and mechanical stresses, see Large Scale Fire Testing.
- **Material performance validation**: Ensuring the chosen materials have been tested and certified for the expected fire conditions.

Relevant Guidelines/Standards

- IEC 60529; 62619; 62933-5-2
- ANSI/CAN/UL 1973
- ANSI/CAN/UL 9540
- NFPA 70; 855
- IFC

Are They Sufficient/Exhaustive?

A minimum of IP2X according to IEC 60529 is generally prescribed (UL 9540, IEC 62933-5-2). UL 9540 also requires IPX3 for enclosures which will be exposed to water and other elements. From experience, this is insufficient for outdoor BESS. Furthermore, the required IP rating for electrical equipment in outdoor locations is typically regulated by national electrical codes based on IEC or other equivalent standards.

Existing codes and standards provide a solid foundation but often fail to address long-term durability and real-world performance that could entail safety conditions. Testing conditions under standards like IEC 60529 must accurately represent the operational environment and installation requirements of the BESS. IEC 60529 permits flexible testing methodologies. When full-scale testing is impractical due to size or configuration, representative parts may be tested. However, this approach risks integration or scaling errors. Interfaces typically achieve the stated IP Code only when properly mated.

Generally speaking, no fire-resistant material is prescribed in the standards. The design depends on the manufacturer and their fire protection strategy.

EASE Recommendation

To ensure a reliable BESS enclosure design, the following should be considered:

- Conduct site-specific risk analyses for environmental and operational factors.
- Use external enclosures rated IP54 or higher for outdoor installations.
- Tailor fire resistance rating to the installation and design, to achieve the desired mitigation
  - Perform real-world fire testing under thermal and mechanical stresses.
- Perform environmental durability tests, such as accelerated ageing. Enclosures should retain their protective features throughout the BESS's operational lifespan of 15-25 years. Factors such as corrosion resistance for metallic enclosures and UV stability for non-metallic materials must be addressed.

- Establish maintenance protocols, including regular inspections and coating reapplications.
- Verify manufacturing quality and installation to ensure proper sealing and alignment of openings.

2.5. Hazard Mitigation Analysis

Hazard Mitigation Analysis (HMA) shall be designed to prevent hazards through appropriate risk identification, analysis, and mitigation.

Relevant Guidelines/Standards

- IEC 60812; 62933-5-1; 62933-5-2
- NFPA 855 (section 4.4)

Are They Sufficient/Exhaustive?

The EU Battery Regulation (EU 2023/1542) requires that stationary BESS shall be safe during their normal operation and include evidence. The Regulation identifies 11 types of risks that, as a minimum to ensuring preservation of life, safety and property, that should be assessed:

1) Thermal shock and cycling[16]
2) External short circuit protection
3) Overcharge protection
4) Over-discharge protection
5) Over-temperature protection
6) Thermal propagation protection
7) Mechanical damage by external forces
8) Internal short circuit
9) Thermal abuse
10) Fire test
11) Emission of gases.

IEC 62933-5-1 offers guidance on analysing various hazards related to BESS, including electrical, mechanical, explosion, electromagnetic, fire, temperature, chemical, and working

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[16] Thermal shock assessment may have limited applicability to BESS, as cell temperatures are actively controlled, and modules are protected by enclosures, making extreme thermal fluctuations unlikely. Nevertheless, this is a common test for many applications, including automotive traction and portable electronics batteries. The idea behind is that “this test shall be designed to evaluate changes in the integrity of the battery arising from expansion and contraction of cell components upon exposure to extreme and sudden changes in temperature, and potential consequences of such changes.” as Annex V of the Regulation explains. Even though thermal management system helps controlling the external temperature of the cells, this test is to ensure that all materials and components used in a cell are compatible with respect to their thermal expansion characteristics. Joule heating affects materials and components inside the cell.

condition hazards. IEC 62933-5-2 specifically focuses on hazard and risk analysis for BESS. NFPA 855, Section 4.4, outlines BESS-specific failure modes and the Hazardous Materials Analysis (HMA) procedures required for their analysis. Although not mandatory in Europe, this document serves as a guideline for analysing specific hazards. IEC 60812 provides a systematic approach to identifying and analysing failure modes through Failure Modes and Effects Analysis (FMEA) and Failure Modes, Effects, and Criticality Analysis (FMECA). While not specific to BESS, this standard offers a structured method for identifying failure modes and their effects on processes or items, both locally and globally.

Additionally, to the items mentioned above, it is recommended that developers, suppliers and other stakeholders work closely to identify, analyse and provide hazard mitigation strategies, as some hazards may be product- or site- specific.

EASE Recommendation

A specific and iterative HMA should be conducted for each project and product in accordance with IEC 62933-5. This analysis must consider the safety of the BESS throughout its entire lifecycle.[17]

Alternatively, the HMA methodology outlined in NFPA 855 can be used, as it eliminates the need for Original Equipment Manufacturers to comply with two different standards. Regardless of the chosen approach, the HMA conducted for a BESS project must comprehensively address all hazards identified by the applicable regulations and cover the environmental impact assessment requirements set by the authorities having jurisdiction.

2.6. Fire Detection and Alarm

Fire detection and alarm systems are essential for ensuring the early warnings of failures. The set up of these systems vary from the one type of BESS to the other, depending on their design and architecture. This results in a detailed risk assessment, addressing site-specific hazards effectively.[18]

Relevant Guidelines/Standards

- IEC 62933-5-2
- EN 54
- NFPA 855
- UL 9540
- FM Global Property Loss Prevention Datasheet 5-33

[17] ESIC Energy Storage Reference Fire Hazard Mitigation Analysis: https://www.epri.com/pages/product/000000003002023089/

[18] Some BESS – especially those following a preventing safety approach – cannot be “tailored” to specific designs (design or hardware requirements). They should not be required to do so in the light of Article 34 TFEU when there exist equivalent safety measures.

Are They Sufficient/Exhaustive?

IEC 62933-5-2 does require a fire alarm in section 7.11.3.4 - where it prescribes protection from fire hazards, however, the design and wiring of the fire alarm system is not further detailed.

EASE Recommendation

To enhance fire safety, the following measures should be considered:

- Install an automatic fire detection system with audible and visible alarms across the site.
- Network in-unit fire panels for centralised monitoring. If absent, use external detection based on manufacturer or site design.
- Integrate fire detection with the Battery Management System or other manufacturer-provided interfaces for real-time risk monitoring.
- Place annunciator panels at site entrances for quick emergency access.
- Use swelling, gas, smoke or heat detection to identify hazards if possible before ignition, or when ignition just started. Advanced options include pressure sensors in cells, electrolyte vapour and smoke detection as well as heat detection. Any detection before fire develops or before smoke even occurs (as heat precedes smoke in a thermal event) will detect hazard occurrence earlier. Activation of early detection systems should activate the F-Stop mechanism in Section 2.7.
- Regularly review detection systems, as they are rarely activated.
- Re-commission the facility only after confirming all risks are mitigated and safety conditions restored.

2.7. F-Stop Mechanism and Other Shut-Down Mechanisms

Fast Stop (F-Stop) mechanisms are designed to prevent battery failures and mitigate the progression of faults. These mechanisms electrically isolate the system, stopping energy transfer and limiting the impact of failures. F-Stop systems integrate with other safety features to ensure the continued operation of critical systems.

Relevant Guidelines/Standards

- IEC 62933-5-2
- UL 9540

Are They Sufficient/Exhaustive?

Existing standards provide a foundation for F-Stop mechanisms without providing detailed requirements on their design, activation thresholds, and integration with other safety systems.

EASE Recommendation

To enhance the effectiveness of F-Stop mechanisms, the following should be considered:

- Design F-Stop systems to disconnect non-critical components during fire or explosion scenarios while preserving the operational functionality of the BMS and firefighting or explosion prevention systems. However, in current designs, the cooling system shuts down when F-Stop is triggered, so its continued operation may not always be feasible.
- Facilitate effective communication between F-Stop mechanisms and the BMS without direct integration, as F-Stop is not currently controlled by the BMS. Instead, the BMS may disconnect certain racks in response to alarms.
- Conduct rigorous testing to validate F-Stop performance across multiple fault conditions, including thermal events and electrical failures.
- Address F-Stop reliability through functional safety assessments (e.g., FMEA, HARA). Compliance with UL 9540 (Class B or SIL2) or IEC 61508 SIL 2, where applicable, should be considered sufficient to determine the need for redundancy. If required, incorporate redundancy to eliminate single points of failure and enhance system reliability during emergencies. Risk analyses shall be mandatory to mitigate risks.

2.8. Explosion Control

Explosion hazards must be assessed separately from fire hazards. Accumulated gases within the BESS or adjacent spaces pose significant hazards, especially when ignition sources or changes in oxygen levels occur (e.g., after fire suppression or venting). When designing explosion control measures, interactions between fire suppression and ventilation systems (passive or active) must be carefully evaluated—for example, triggering an exhaust fan at the same time as releasing an aerosol suppression agent may compromise its effectiveness. Without proper – passive or active – ventilation, gases can accumulate over time, increasing explosion risks. Activation of fire suppression equipment designed to mitigate fire risk should not harm the effectiveness of the equipment for the explosion risk. If necessary, priority levels should be defined between fire suppression and explosion prevention.

Explosion mitigation features such as deflagration panels and ventilation should be validated through physical testing and/or supported by a modelling analysis. While a testing procedure has not yet been published, many internationally recognised testing laboratories have experience with explosion testing in BESS.

Effective explosion control and prevention measures are critical to preventing catastrophic events. The fault tree below illustrates some scenarios that can lead to explosions (without being exhaustive, e.g. does not provide for the possibility of venting):

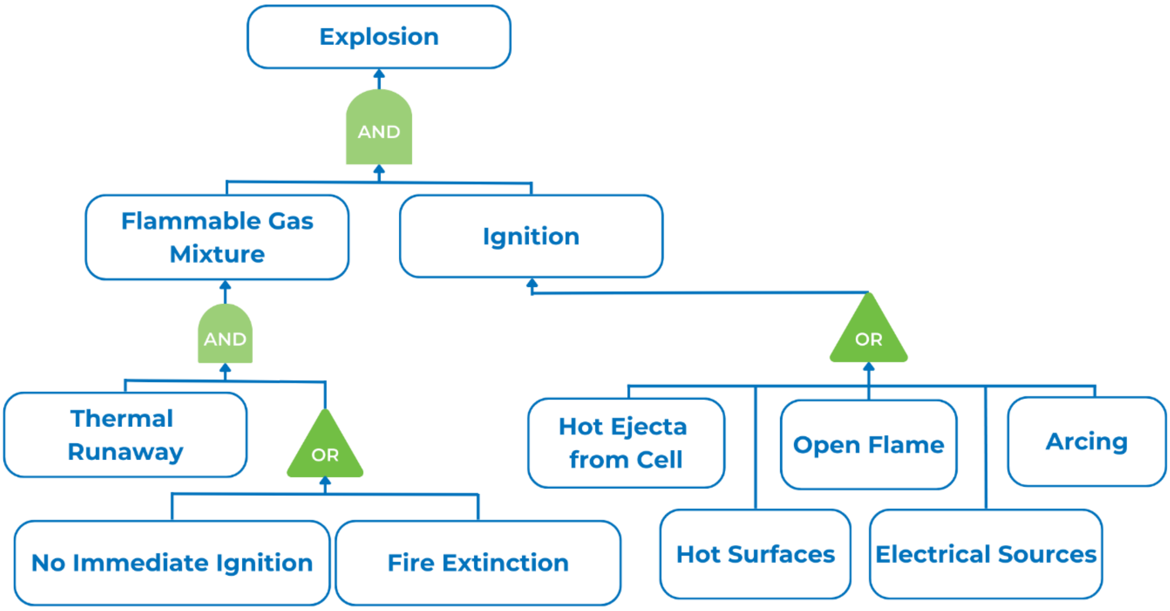

Figure 3: Fault tree showing scenarios that could lead to an explosion, adapted from E. Archibald, Fire & Explosion Hazards due to Thermal Runaway Propagation in Lithium-Ion Battery Systems, 2021.[19]

Relevant Guidelines/Standards

- IEC 62933-5-2

Explosion protection strategies can be categorised into three main approaches, each with its own applicable standards:

Safety parameter	Standard	Description
Explosion prevention by deflagration venting	NFPA68 – Standard on Explosion Protection by Deflagration Venting	Passive ventilation systems to provide deflagration venting, such as deflagration panels. Deflagration panels are mechanical pressure reliefs which allows to limit explosion consequences in case of a critical off-gas mixture gets ignited and to control blast direction. These vents are “passive”, meaning that they are not actuated but rather, they open and close (under the effect of the pressure caused by gases) through clips e.g.

[19] Archibald, E. *Fire & Explosion Hazards due to Thermal Runaway Propagation in Lithium-Ion Battery Systems.* 2021.

Explosion protection by active ventilation systems	NFPA69 - Standard on Explosion Prevention Systems	Active ventilation systems to provide deflagration prevention, such as Fans/Ventilators. Fans/ventilators are active components which are used to ventilate the BESS in case of a critical off-gas mixture from cell thermal runaway.
Explosion prevention by passive venting and engineered explosion control system	NFPA 855 9.6.5.6.4 -Engineered explosion-controlled systems	As in "Explosion prevention by deflagration venting" above, plus an engineered explosion control system, designed and developed using engineering principles and practices to meet specific safety standards.

The reference standard for BESS explosion control is NFPA 855, supported by Fire and Risk Alliance's BESS explosion control guidance (2023/2026).[20] NFPA 855:2023 permits the use of either NFPA 68 or NFPA 69 for engineered explosion control systems. However, the proposed NFPA 855:2026 update will make NFPA 69 the primary standard, with NFPA 68 as optional supplementary support.[21] Both NFPA 68 and NFPA 69 outline active and passive explosion prevention strategies, specifying venting solutions to mitigate risks from cell off-gassing and prevent catastrophic failures.

Manufacturers must demonstrate compliance with the following:

- **Deflagration Venting per NFPA 68 (NFPA 855 9.7.6.7.3.1):**
  - Design venting systems to manage overpressure caused by explosive gases or dust.
  - Equip BESS with deflagration panels to safely relieve internal pressure during gas ignition.
  - Ensure pressure relief mechanisms remain intact and do not create projectiles during deflagration.
- **Active Venting per NFPA 69 (NFPA 855 9.7.6.7.3):**
  - Maintain gas concentrations below the Lower Explosive Limit (LEL).
  - Use active venting systems to mitigate flammable atmospheres.
  - Integrate explosion prevention strategies into emergency response plans.
  - Clearly identify venting panel locations for operators and firefighters to minimise injury risks.
  - Conduct regular maintenance and testing of ventilation systems as these are safety-critical components.

[20] Sandia National Laboratories. PR2023_300_Paiss_Matthew_Safety-Reliability. Available at: https://www.sandia.gov/app/uploads/sites/82/2023/10/PR2023_300_Paiss_Matthew_Safety-Reliability.pdf. Accessed: 31 January 2025.
[21] Sandia National Laboratories: PNNL Energy Storage Introduction, Page 7. Accessed 31 January 2025

- **Engineered explosion control systems (NFPA 855 9.6.5.6.4):**
  - Performance based explosion control systems designed to ensure no hazardous pressure waves, debris, shrapnel, or enclosure pieces are ejected.
  - NFPA 855 recognises engineered explosion control systems in lieu of NFPA 68 and 69 systems, where validated through large scale explosion testing and an engineering evaluation.

Are They Sufficient/Exhaustive?

Existing standards, such as NFPA 855, provide strong guidance on explosion control. By following them, BESS manufacturers can reduce risks to personnel and structures, improve fire safety, and ensure compliance with fire codes and regulations.

While these standards cover key aspects of active and passive explosion prevention, they may not fully address the specific configurations and operational environments of all BESS designs. Manufacturers often exceed these requirements with customised solutions, such as passive venting and ignition systems. More detailed recommendations can be found in the Explosion Control Guidance for Battery Energy Storage Systems by Fire & Risk Alliance.[22]

Currently, there are no direct ISO or IEC standards specifically addressing explosion control for BESS. However, several European standards provide guidance on related topics. EN 14491:2012, which covers dust explosion venting protective systems, outlines vent sizing requirements to protect enclosures from internal pressure effects, flames, and recoil forces while considering the impact of vent ducts. EN 14373:2021 defines requirements for explosion suppression systems, including the evaluation of effectiveness, scaling, and design tools, as well as installation and maintenance guidelines. EN 14797:2006 specifies requirements for explosion venting devices used to protect enclosures from internal explosions, covering aspects such as design, inspection, testing, and marking.

EASE Recommendation

To ensure effective explosion hazard mitigation, all internationally recognised fire safety approaches should be permitted, including explosion prevention systems, explosion protection systems, and engineered explosion control systems. The regulatory framework should remain technology-neutral, allowing both passive and active safety architectures, provided they comply with or exceed established safety standards.

To improve explosion prevention and control, the following principles should be applied:

- Implement a combination of explosion prevention and protection systems, ensuring they are tailored to the specific BESS designs and architectures available on the market.
- Use NFPA 69 and NFPA 68 (if implemented) as frameworks to design effective venting and prevention solutions.

[22] Fire & Risk Alliance. Explosion Control Guidance for Battery Energy Storage Systems. 2024. Available at: https://bess-sdk.com/resources/whitepapers/bess-explosion-control-guidance/. Accessed: 4 December 2024.

- Prioritise real-world testing and risk assessments to validate system performance under expected operating conditions.
- Provide clear documentation and training for operators and first responders on system functionality and emergency procedures.

2.9. Fire Safety Strategy

Fire safety strategies should consider a range of possible fire scenarios which should be captured in a site-wide risk assessment (e.g. external fire scenarios) beyond thermal runaway, as other failure modes (e.g., electrical faults, mechanical damage, or external fires) may also be relevant. The design should also take into account factors such as site, system and cell-level characteristics, including the specific cell chemistry and cathode composition. An effective action plan in the event of a fire should align with the battery chemistry and the results of the manufacturer's certification and validation tests.

Below, the safety strategies are categorised into two scenarios: battery fires and non-battery fires.

2.9.1. Battery Fires

Some BESS design/architecture follow a controlled burning approach during a thermal runaway event, where application of water shall be limited to cooling adjacent enclosures, buildings, or nearby exposures.[23] This method can be often the preferred fire action plan, as it avoids:

- Fire suppression which can increase the explosion hazard.
- Avoids contaminating nearby soils or groundwater.
- Ensures the safety of firefighters by eliminating the need for direct intervention.
- Potential for reignition and stranded energy.

If any kind of automatic fire suppression strategy is chosen by the manufacturer, it must be evaluated by physical tests for higher severity outcomes such as explosions.[24]

Relevant Codes and Standards

- UL 9540A Unit level test procedure.
- UL 9540A installation level test procedure, only applicable if UL9540A Unit level test failed and product design includes a fire suppression system.

[23] The difference in the behaviour of water versus the different chemistries should be analysed since, for example, NMC effectively produces O_2 in its decomposition and therefore the fire cannot be extinguished by suffocation while LFP does not.
[24] Annex G 6.1 of NFPA 855.

- Large Scale Fire Testing per NFPA 855:2026. Although not yet published, NFPA855:2026 proposal is expected to update the Large-Scale Fire testing procedure.[25]

Are They Sufficient/Exhaustive?

The UL 9540A test methods at the module, unit and installation level evaluates the effects of cell-to-cell thermal runaway propagation within the device under test (DUT). While the requirement to create a propagating thermal runaway condition is an extreme abuse test, it is not indicative of a catastrophic failure scenario and does not require a fully developed fire condition. In particular, UL 9540A is not necessarily synonymous with fire on batteries. A Large-Scale Fire Test requires that a fully developed fire condition be created and is often required, in addition to, UL 9540A unit level testing if it did not result in a fully developed fire.

EASE Recommendation

It is imperative that regulation allows for flexible fire safety strategies adapted to different BESS designs and architectures. While installation environment requirements may be subject to national or local regulations, fire safety strategies should allow for adaptability to accommodate various system designs. Controlled burning is a viable approach, as confirmed throughout the world, and evidence from large-scale fire tests must support this decision.

Direct water injection is another viable method to prevent fire propagation inside a container, where system design allows for it (e.g. dry pipe installed). However, fire fighters should not open the BESS enclosure to actively fight a thermal runaway once initiated within a battery cell.

It is good practice for BESS manufacturers to provide evidence of the effectiveness and reliability of the suppression method by providing a third-party report.

2.9.2. Non-Battery Fires

Many fires of batteries are caused by components not directly related to batteries. A non-battery fire should not cause an escalation or initiation of thermal runaway in the battery. Non-battery fires may find their origin in electrical incidents, asset-external origin, lighting, earthing, etc.

Several methods listed in NFPA 855:2023 can be used as fire suppression systems. The most appropriate one shall be determined in accordance with the manufacturer's non-battery fire safety strategy and product design, which may include the use of clean agent gases and condensed aerosol, among others. If any kind of suppression strategy is chosen by the

[25] The American Clean Power Association. NFPA855 Safety Report. 2024.

manufacturer, it must be evaluated by physical tests to ensure against higher severity outcomes such as explosions.[26]

Relevant Guidelines/Standards

- IEC 60364
- IEC 62933-5-2
- NFPA 855

Are They Sufficient/Exhaustive?

Non-battery fire risks must be included in the risk assessment. At a minimum, a Fire Risk and Explosion Analysis (FERA)[27] should simulate these scenarios.

EASE Recommendation

Where the risk of fire in non-battery related components is unacceptable, i.e., if there is a risk of fire/heat reaching the battery modules, the fire origin could be detected by a suitable fire/heat detection and fixed extinguishment system placed inside or outside as the BESS design allows for it.

The battery must be appropriately separated from other flammable components to avoid the spread of fire, as specified in Section 2.4 of this document.

2.10. Large Scale Fire Testing

A battery fire in a BESS shall not result in a fire to spread to adjacent units. Large-scale fire testing shall provide evidence of this and determine the required spacing between BESS units.

Relevant Guidelines/Standards

- UL 9540A Unit Level Test
- NFPA 855:2026 Large-Scale Fire Test
- UN 3536 (Lithium Batteries in Cargo Transport Units, Special Provision 389)

Are They Sufficient/Exhaustive?

NFPA 855:2023 currently references the UL 9540A test regimen. While UL 9540A is considered an extreme abuse test, it typically does not result in a catastrophic failure event based in part on the active and passive protection strategies used to mitigate the development of a

[26] Annex G 6.1 of NFPA 855

[27] Arthian website. Fire and Explosion Risk Analysis (FERA). Available at: https://www.arthian.com/service/risk-analysis-studies/fire-and-explosion-risk-analysis-fera/. Accessed: 31 January 2025.

catastrophic failure from a propagating failure scenario. To evaluate a catastrophic failure scenario, the NFPA 855:2026 will incorporate a requirement for UL 9540A testing and a large-scale fire test. The UL 9540A technical committee is currently developing a new test method for conducting a large-scale fire test to evaluate such a failure mode. It is recommended that manufacturers undergo both the UL 9540A test regimen and a large-scale fire test.

EASE Recommendation

To ensure safety and compliance, BESS manufacturers must provide evidence of adherence to NFPA 855:2026 Large-Scale Fire Testing (or equivalent). In case of other methods chosen, their evidence has to be precisely described and verified. The test report should confirm that no fire propagation occurs between BESS units or in advanced solutions no fire propagation occurs between sub-units (e.g., packs) of a BESS to prevent container fire. This evidence helps site owners, customers, and authorities understand BESS fire behaviour.

2.11. List of Recommendations by Topic for Section 2

Topic	EASE Recommendations
Battery System (cell/module/pack/rack):	• Design battery systems to adhere to the failsafe principle and minimise risks during normal and failure conditions. • Implement site-specific emergency plans and first responder training.
Battery Management System:	• Continuously monitor critical parameters such as voltage, current, and temperature in real-time. • Incorporate advanced diagnostic tools and predictive maintenance features. • Ensure seamless compatibility between the BMS and other system components. • Expand BMS testing to include large-scale operational scenarios to enhance reliability.
Thermal Management System:	• Ensure thermal management system remains operational during pre-defined and specific critical safety conditions. • Integrate leakage alarms with the BMS for liquid cooling systems. • Conduct risk assessments for cooling systems and validate their designs through recognised certification processes.

BESS Enclosure Design:	• Use enclosures rated IP54 or higher for outdoor installations. • Align fire resistance with mitigation plans and utilise non-combustible materials. • Conduct environmental durability tests, such as accelerated ageing. • Establish maintenance protocols, including regular inspections and reapplications. • Ensure high manufacturing quality and proper sealing of enclosures to prevent ingress.
Fire Detection and Alarm Systems:	• Install automated fire detection systems capable of providing early warnings through audible alarms. • Integrate site-level fire panels for centralised monitoring and control. • Link fire detection systems with the BMS – or other relevant interfaces provided by manufacturers– for real-time risk monitoring and rapid response. • Place annunciator panels at site entrances for emergency responders. • Recommission facilities only after all risks have been mitigated and safety conditions restored.
Hazard Mitigation Analysis (HMA):	• Conduct iterative HMA for each project and product lifecycle phase. • Follow IEC 62933-5 and EU Regulation 2023/1542 for hazard identification and mitigation. • Address all hazards identified in applicable regulations and environmental impact assessments.
F-Stop Mechanism:	• Design F-Stop systems or other shut down mechanisms to disconnect non-critical components during fire or explosion scenarios while preserving the operational functionality of the BMS and firefighting or explosion prevention systems. However, in current designs, the cooling system shuts down when F-Stop is triggered, so its continued operation may not always be feasible. • Facilitate effective communication between F-Stop mechanisms and the BMS without direct integration, as F-Stop is not currently controlled by the BMS. Instead,

		the BMS may disconnect certain racks in response to alarms. • Conduct rigorous testing to validate F-Stop performance across multiple fault conditions, including thermal events and electrical failures. • Address F-Stop reliability through functional safety assessments (e.g., FMEA, HARA). Compliance with UL 9540 (Class B or SIL2) or IEC 61508 SIL 2, where applicable, should be considered sufficient to determine the need for redundancy. If required, incorporate redundancy to eliminate single points of failure and enhance system reliability during emergencies.
Explosion Control:		• Allow different explosion prevention and protection systems adapted to various BESS design. • Follow NFPA 68 (where implemented) for passive deflagration venting and NFPA 69 for active ventilation systems. • Allow for passive venting (NFPA 68) and igniters (UL 9540-A tested and custom tested) with engineered explosion system (NFPA 855). • Conduct real-world testing to validate performance under operational conditions and allow for custom-made testing when no standard test is available. • Provide clear documentation and training for operators and first responders on system functionality and emergency procedures.
Fire Safety Strategy	**Battery fires:**	• Adopt controlled burning strategies where contamination risks or firefighter safety concerns take precedence. • Base this approach on evidence from risk analyses, large-scale fire tests (or manufacturer published emergency response guides (ERGs)).
	Non-Battery Fires:	• Protect non-battery components with fire detection and extinguishing systems if there is a risk of fires spreading to battery modules. • Ensure batteries, where design permits it, are separated from flammable components to prevent fire propagation.

Large-Scale Fire Testing:	• Comply with NFPA 855:2026 Large-Scale Fire Testing requirements (or equivalent). • Provide evidence that no fire propagation occurs between BESS units to ensure site safety.

3. Site Safety

This chapter covers safety measures for BESS sites, including perimeter security, fire protection, and hazardous material containment. It focuses on mitigation measures to reduce risks and ensure rapid emergency response. It highlights the importance of unit spacing to prevent fire propagation and the need for effective containment.

3.1. Location Requirements

BESS sites must comply with local and national safety regulations while addressing specific risks, such as fire hazards, water runoff, and proximity to nearby communities. Site assessments should account for wind speed and direction, escape routes, and firefighting plans.

Relevant Guidelines/ Standards

- IEC 62933-5-2
- NFPA 855
- UL 9540A

Are They Sufficient/Exhaustive?

The guidelines provide robust safety practices that address core risks, such as fire propagation and emergency planning. However, local regulations and environmental conditions must supplement these standards to account for site-specific challenges, such as urban proximity or extreme environmental conditions.

These standards are not mandatory in the European Union but are a good guidance to realise safe installation.

EASE Recommendation

Site assessments should be conducted at project inception and revisited periodically. These assessments could address:

- Fire and smoke risks for nearby communities.

- Drainage systems for water runoff, including municipal water integration for firefighting.
- Clear emergency escape routes and on-site firefighting strategies.
- Environmental risk for the site has to be assessed and mitigated.
- Quantifiable measurements that trigger broader civic response (road closures, shelter in place).

3.2. Fencing

Fencing prevents unauthorised access to BESS sites while maintaining airflow and exhaust efficiency - examples of fencing can be security barriers and/or landscaping. Remote sites require robust systems with 24-hour closed-circuit television (CCTV) surveillance. Fencing materials* and distances should align with the installation's size and risk profile.

**High-security fence, such as steel palisade or steel weldmesh, is frequently used, with acoustic fencing available depending on the site's location.*

Relevant Guidelines/Standards

- IEC 62933-4-1
- ISO 13857
- NFPA 70 (NEC) / 855 (Section 4.7.6)

Are They Sufficient/Exhaustive?

NFPA 855 offers a solid foundation for access control, ensuring that sites are protected from unauthorised entry. However, the standard does not provide detailed guidance on fencing materials, advanced security measures, or risks unique to specific locations, such as wildlife interference or high-crime areas.

EASE Recommendation

Carry out comprehensive site inspections to assess fencing requirements, considering whether the site is hybrid/mixed or standalone. This shall include:

- Local regulations and environmental factors.
- Risks from high-crime or wildlife-prone areas.
- Integration with monitoring systems like 24-hour CCTV and motion detectors.

3.3. Water Availability at Site

The decision to demand water availability near BESS should be made in consultation with local authorities to ensure compliance with safety standards, regulations, and firefighting preparations.

Water remains a standard practice for fire departments during an emergency. Although first responders can use water to help prevent BESS to BESS propagation, they should not open the BESS enclosure to actively fight a thermal runaway once initiated within a battery cell.

The presence of water on-site should be determined by local jurisdiction. Below are advantages and disadvantages to be considered:

Factor	Advantages[28]	Disadvantages[29]
Fire Suppression	Can reduce peak heat load when supplied through dry piping into the BESS enclosure (if designed by OEM)	Limited suppression effectiveness—may prolong the fire event without fully extinguishing it
Cooling Adjacent Units	Helps prevent cascading fire propagation to nearby BESS units or infrastructure	Excessive use may lead to water runoff carrying toxic byproducts - this also applies to Fire Suppression[30]
Controlled Burning Strategies	Fire brigades can use water to manage a controlled burn, preventing spread to vegetation or critical assets	Requires careful planning to avoid unintended thermal effects
Toxic Emission Mitigation	Can dilute hazardous emissions, reducing environmental and health impacts	Can spread contaminants if runoff is not properly contained
Electrical Safety	-	High conductivity increases risk of electrical shock or short circuits[31]
Thermal Runaway Risk	-	May intensify thermal runaway under certain conditions[32]

Relevant Guidelines/Standards

- IEC 62933-5-1
- ISO 14001
- NFPA 855: 2023/2026 (proposal)
- National Fire Chiefs Council (NFCC) - Grid-Scale Battery Energy Storage System Planning: Guidance for FRS (2022)
- 2024 International Fire Code Section 1207

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[28] Ineris. Moyens de maîtrise des risques des batteries pour les applications conteneurisées. 2023
[29] ScienceDirect. A Review of Thermal Runaway Prevention and Mitigation Strategies for Lithium-Ion Batteries. Available at: https://www.sciencedirect.com.
[30] Assessment of Run-Off Waters Resulting from Lithium-Ion Battery Fire-Fighting Operations
[31] A review of thermal runaway prevention and mitigation strategies for lithium-ion batteries - ScienceDirect
[32] What causes lithium-ion battery fires? Why are they so intense? And how should they be fought? An expert explains

Are They Sufficient/Exhaustive?

The guidelines provide a strong starting point for ensuring adequate water resources. However, the necessity for water supply and the method of availability depends heavily on local jurisdiction and specific firefighting strategies, requiring coordination with local fire departments.

EASE Recommendation

Coordinate water availability with site-specific risks. Focus should be put on:

- Providing on-site reserves or connecting to public supplies.
- Consulting fire authorities to match resources with suppression needs.
- Ensuring compliance with local water management and safety regulations.

3.4. Hazardous Liquids Containment

Wastewater containment systems must prevent environmental contamination from firefighting runoff, accidental spills, and leaks from cooling and transformer systems. Proper containment should also manage leachates from extinguishing water and toxic byproducts, including oil and glycol spills. Understanding the specific sources of these spills is essential for implementing targeted mitigation strategies:

- **Thermal management systems**: BESS installations often utilise equipment that circulates refrigerants through closed-loop systems. While leaks are uncommon, system failures can occur, leading to refrigerant leaks. These leaks can pose environmental hazards if not promptly addressed.
- **Batteries**: Li-ion batteries are designed to contain electrolyte leakage from within the cell. However, electrolyte leakage can indicate cell failure and potential degradation, necessitating immediate attention.
- **Oil transformers**: Some BESS configurations incorporate mineral oil transformers. Leaks from these transformers can lead to soil contamination, underscoring the need for robust containment measures.
- **Liquids associated with firefighting**: In the event of a fire, water used for suppression can mix with chemicals released during combustion, resulting in contaminated runoff. This runoff can enter drainage systems and potentially contaminate water catchment areas if not properly managed.

Relevant Guidelines/Standards

- IEEE C57.12
- NFPA 30 / 70 (NEC) / 855

- OECD Guidelines: Chemical impact testing[33]

Are They Sufficient/Exhaustive?

The standards address essential containment practices, including secondary containment for hazardous liquids. However, they lack comprehensive guidance on managing chemical effluents and circular economy initiatives, such as end-of-life battery disposal and recycling.

EASE Recommendation

Implement strong containment measures to properly handle wastewater. Ensure the systems include:

- Secondary containment for transformer oil leaks, in compliance with NFPA 30, NFPA 850, and IEEE C57.12.
- Spill trays or bund walls to capture glycol leaks from liquid cooling systems.
- Oil-water separators and filtration to prevent hazardous discharge into the environment.
- Leak detection sensors to monitor potential spills and ensure timely response.
- Proper drainage and wastewater treatment to handle contaminated runoff from fire suppression and prevent pollution of soil and water sources.

3.5. Container Spacing

Proper container spacing minimises fire propagation risks and ensures safety during normal and emergency operations. Spacing must comply with local regulations and be supported by risk analyses.

Relevant Guidelines/Standards

- IEC 62933-5-2
- NFPA 855
- UL 9540(A)

Are They Sufficient/Exhaustive?

NFPA 855 explains that in a large-scale fire test, there should be no propagation between enclosures, which may influence the distance between enclosures needed but does not necessarily require fire condition. UL9540A also includes testing at unit level which aids in better understanding and managing thermal propagation on site.

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[33] OECD. Guidelines for the Testing of Chemicals. Available at: https://www.oecd.org/en/topics/sub-issues/testing-of-chemicals/test-guidelines.html

EASE Recommendation

Container spacing at BESS sites should be determined through a comprehensive risk-based analysis that accounts for:

- Fire protection, including suppression system access.
- Emergency response measures including fire brigade response time and capabilities.
- Installation-specific factors like BESS enclosure fire rating, size, capacity, and battery chemistry.
- Spacing necessary for preventive and corrective maintenance.
- Insights from large-scale fire tests and simulation data to estimate the required clearance for preventing fire propagation under standard conditions.

3.6. Spacing Towards Power Conversion System

Safe distances between BESS containers and PCS are critical to preventing electrical and fire hazards. Power electronics, transformers, and PCS equipment introduce additional risks such as heat generation, electrical arcing, and oil leakage from transformers, all of which must be considered in the site design.

Relevant Guidelines/Standards

- IEC 62477-1:2022
- NFPA 850 / 855: 2023/2026 (proposal)

Are They Sufficient/Exhaustive?

The standards provide adequate guidance for standard installations. However, they fall short in addressing risks associated with large-scale systems or innovative PCS designs that may require more complex risk assessments.

EASE Recommendation

Spacing in between Power Conversion Systems (PCS) should minimise risks. Key measures for this include:

- Maintain distances based on flammability and arcing potential.
- Include fire barriers in high-risk areas.
- Regularly update designs to align with PCS technology advancements.

3.7. Spacing Towards Environment (Buildings / Fence / Vegetation)

Spacing requirements for BESS installations are regulated by national fire codes, which vary by country. Ensuring adequate separation between BESS containers and surrounding infrastructure is essential for protecting buildings, populations, and ecosystems. Proper spacing helps mitigate risks such as fire propagation, hazardous emissions (including gases and particulates), and structural damage in the event of an incident.

Relevant Guidelines/Standards

- NFPA 855
- ISO 31000 / 14001
- EN 61000-6-3

Are They Sufficient/Exhaustive?

The standards effectively address basic environmental and population safety concerns, such as fire spread and buffer zones. However, they provide limited coverage of unique challenges, including wildfire-prone areas or high-density urban installations with constrained space.

EASE Recommendation

Key spacing considerations include:

- Clear vegetative barriers to prevent fire spread.
- Buffer zones for buildings and fences to minimise heat damage.
- Engage authorities and communities to address risks in urban and rural settings.

3.8. Gas/ Smoke/ Noise Emissions

When analysing the risk arising from the emission of, hazardous emissions (including gases and particulates), it is first important to know what the source of the gas may be:

- **Cells**: During a cell fire, the internal materials of the cell decompose and certain hazardous gases are derived. These generated gases are derived from the components that make up the cells: anode, separator, cathode and electrolyte. Due to the wide variety of chemical compositions used by different cell manufacturers, the gases formed after a fire can vary.
- **Other components of the BESS**: In addition to the batteries themselves, the BESS includes a number of other metallic and plastic materials that, when subjected to high temperatures, can generate hazardous gases. These include plastic materials used in battery casings or other components, as well as metals in connections, cables and structures of the BESS.
- **Coolant**: On the other hand, gases can also be generated as a result of a fire, as well as possible leaks in the cooling systems, which represent a hazard. As previously mentioned, storage systems consist of refrigeration systems which, after a failure, can generate hazardous gases.

BESS emissions management must differentiate between normal operations (e.g., noise) and emergencies (e.g., gas and smoke). Toxic emissions and evacuation needs should be factored into emergency response plans, just as they are for other hazardous fires. Mitigation of environmental contamination must also be incorporated, acknowledging that such situations are exceptional.

Relevant Guidelines/Standards

- IEC 62933 -5-2 / 63056 / 144
- ISO 3744
- EN 50574
- UL 9540A
- Environmental Noise Directive (Directive 2002/49/EC)

Are They Sufficient/Exhaustive?

The existing guidelines offer a solid foundation for emissions control (including smoke, gases, and noise). However, they require regular updates to address evolving technologies and variations in local regulations, particularly for noise and gas emissions in sensitive areas.

EASE Recommendation

To ensure safety and minimise impacts, emissions from BESS fires should be managed as follows:

- In emergency response plans, include evacuation, first-responder safety, and strategies based on thermal runaway research.
- Mitigate noise impacts by complying with local noise regulations. A BESS development planning application should include an Acoustic Impact Assessment, typically reviewed by the Environmental Health Officer (EHO) or an equivalent authority. The energy storage system must meet strict noise limits set by local authorities to prevent adverse effects on residential areas.
- Align with local and regional regulations, balancing operations with community well-being.

3.9. List of Recommendations by Topic for Section 3

Topic	EASE Recommendations
Location Requirements:	• Conduct site assessments for environmental and safety risks. • Address proximity to communities, water runoff, and scaled regulations.
Fencing:	• Tailor fencing to local regulations, site characteristics, and security needs. • Integrate surveillance systems to enhance security.

Water Availability:	• Ensure water resources align with fire suppression strategies. • Consult local fire authorities to determine water supply requirements.
Wastewater Containment:	• Install systems to manage firefighting runoff and prevent contamination, only if water based extinguishing systems are present. Otherwise, procedures must be included in the emergency plan. • Include sealed containers for floods or fire operations.
Container Spacing:	• Use risk-based analysis to determine spacing. • Address fire suppression access and system-specific characteristics.
Spacing Towards Power Conversion System (PCS):	• Maintain safe distances to mitigate electrical and fire risks. • Incorporate fire barriers where necessary.
Spacing Towards Environment:	• Clear vegetative barriers and establish fire safety perimeters. • Engage stakeholders to ensure urban and rural safety compliance.

4. Personnel Safety

This chapter focuses on protecting personnel working with BESS systems. It includes guidelines on training, procedures, and emergency plans. The chapter highlights the use of personal protective equipment and safe work practices to reduce exposure to electrical hazards and fires.

4.1. Emergency Response Plan

An effective emergency response plan (also emergency operation plan, safety manual or similar) is essential for ensuring personnel safety and mitigating risks during incidents. Such plans are often legally mandated and must align with recognised standards and guidelines.

Relevant Guidelines/Standards

- IEC 62485:2020 / 62933-5-2:2020.
- ISO 22320

- NFPA 855
- First Responders Guide to Lithium-Ion Battery Energy Storage System Incidents, American Clean Power Association, 2023.
- New York Battery Energy Storage System Guidebook, New York State Energy Research and Development Authority (NYSERDA), 2024.

Are They Sufficient/Exhaustive?

ISO 22320 highlights emergency response planning, including integration with local fire services and detailed contingency measures for fire or chemical leaks.

EASE Recommendation

Emergency response plans must prioritise personnel safety and align with recognised standards. They should incorporate practical, evidence-based strategies to minimise risks during incidents:

- When a large-scale fire testing shows that the fire is confined to a single BESS unit, firefighters should adopt a defensive approach. Allowing the fire to self-extinguish reduces risks to responders.
- When necessary, cool adjacent units or exposed assets using fog nozzles with a wide-angle cone. This approach is advisable when large-scale fire testing has not been performed or when additional cooling is required.
- Personnel should never manually open the doors of a smoking or burning BESS. If access is needed, use remote or robotic equipment from a safe distance to avoid creating an explosive atmosphere by introducing oxygen.

4.2. Training (Personnel /Firefighters)

Personnel training must prioritise emergency response preparedness for all staff. Once finalised, the emergency response plan should be shared with local firefighters and relevant authorities in the designated area to ensure coordination and clarity during emergencies.

Relevant Guidelines/Standards

- IEC 62040-1
- ISO 45001:2018 - Occupational Health & Safety Management Systems — Requirements with guidance for use
- NFPA 855

Are They Sufficient/Exhaustive?

The current standard is sufficient as a general framework but not exhaustive for BESS-specific hazards and training needs. It is advised to develop industry-specific training modules that align with this standard but also address high-voltage systems, thermal events, and battery chemical hazards in detail.

EASE Recommendation

Training programmes must be based on the established emergency response strategy, which is specifically designed for people at BESS locations. Key features include:

- Develop tailored training programmes for emergency responders and site personnel, aligned with national and regional standards.
- Ensure firefighters and first responders receive comprehensive, role-specific instruction for effective emergency response.
- Update training regularly to reflect new battery technologies and evolving safety practices.
- Conduct annual refresher sessions, including on-site exercises and tabletop drills.

4.3. Public Access

Restricting public access to BESS sites is critical to prevent unauthorised entry and reduce risks of injury or interference. It is also physically not possible to enter containers, since it is only to specialised personnel. There should be a no access sticker in the entrance along with warning signs of hazards.

Relevant Guidelines/Standards

- IEC 62933-4-1
- ISO 13857
- UL 9540
- NFPA 855

Are They Sufficient/Exhaustive?

The listed standards provide a solid foundation for public access restrictions, but they may not be exhaustive. UL 9540 and NFPA 855 address access control, while ISO 13857 and IEC 62933-4-1 focus on safety measures but do not emphasise public access. Additional security measures like fencing, surveillance, and controlled access may be needed, along with compliance with local regulations.

EASE Recommendation

The following measures will improve public safety and security at BESS sites:

- **Perimeter security**: Use 24-hour surveillance, secure fencing, and controlled entry gates, especially for BESS locations in urban areas, to effectively exclude the public and limit unauthorised access.

- **Community engagement:** Local governments should conduct risk communication campaigns as part of their Seveso III compliance. These efforts should educate the public about restricted zones, safety practices, and emergency plans, raising awareness of potential hazards and access restrictions.

4.4. Control and Maintenance

Safe operation and maintenance are vital for preventing accidents and ensuring the longevity of BESS. Maintenance activities should be guided by alarms or performance indicators, along with regularly scheduled tasks, minimising unnecessary exposure to risks.[34]

Relevant Guidelines/Standards

- IEC 62485-5
- ISO 50001 / 55000 (Asset Management)
- NFPA 70 B / 70E

Are They Sufficient/Exhaustive?

These standards provide a solid foundation for maintenance practices and high-voltage safety. However, they do not address predictive maintenance or advanced monitoring systems commonly used in modern BESS installations.

EASE Recommendation

For the control and maintenance of BESS containers, the following actions should be considered:

- Implement a permit system to ensure maintenance tasks are performed safely.
- Monitor BESS facilities 24/7 using remote systems and Closed-Circuit Television (CCTV), especially in remote locations.
- Prohibit lone working during high-voltage maintenance and ensure strict adherence to safety protocols.

4.5. Recommended Personal Protection Equipment

Ensuring proper use of personal protective equipment (PPE) is crucial for safety during both maintenance and emergency situations. Required PPE includes:

- Helmets
- Gloves (electrically insulated)

[34] EPRI Energy Storage Operations and Maintenance Tracker: https://www.epri.com/research/products/3002019222

- Protective clothing for high-voltage systems and electric arc protection
- Boots (hard-toed)
- During fires, breathing protection
- Other relevant protective gear, especially for heavy lifting of larger battery modules

Relevant Guidelines/Standards

- IEC 61482-2
- ISO 20345 / 374-1 / 45001
- EN ISO 11612
- NFPA 70E
- ASTM F1506
- OSHA 1910.269
- CSA Z462

Are They Sufficient/Exhaustive?

Current standards provide a strong basis for general PPE requirements. However, they lack detailed guidance for newer battery technologies and ergonomic considerations for handling large modules.

EASE Recommendation

A comprehensive PPE system should be established, tailored to both maintenance and emergency scenarios. This system must be integrated into the emergency response plan, ensuring all personnel are equipped to manage routine and emergency situations effectively. The responsibilities for maintenance and emergency situations should be clearly defined, with distinct PPE requirements for each.

4.6. List of Recommendations by Topic for Section 4

Topic	EASE Recommendations
Emergency Response Plan:	• Share emergency response plans with local fire services to familiarise them with site-specific hazards and procedures. • Provide site-specific training for local fire brigades, particularly in remote areas. • Develop national-level guidelines to standardise emergency response preparation. • Align plans with recognised standards: NFPA 855, ISO 22320, and IEC 62485:2020.

Training (Personnel/Firefighters):	• Develop training modules tailored to BESS-specific hazards, such as high-voltage systems, thermal events, and chemical risks. • Share emergency response plans with firefighters and relevant authorities to ensure coordination during incidents. • Adapt training programmes to regional regulations and advancements in battery technology. • Follow ISO 45001 for general training but supplement with BESS-specific content.
Public Access:	• Restrict public access to BESS sites with secure fencing, controlled gates, and 24/7 surveillance. • Use clear signage, such as "No Access" stickers, at entry points to warn against unauthorised entry. • Engage local governments to communicate public safety measures as part of compliance with Seveso III. • Implement guidelines from UL 9540 and NFPA 855 for access control.
Control and Maintenance:	• Monitor BESS systems 24/7 using remote control systems and CCTV, particularly for remote installations. • Use a permit system to ensure maintenance tasks are performed safely. • Schedule maintenance activities based on alarms or performance indicators to minimise risk exposure. • Follow strict high-voltage protocols, including prohibiting lone working during maintenance. • Adhere to standards like ISO 55000 for asset management and NFPA 70E for electrical safety.
Personal Protective Equipment (PPE):	• Establish a comprehensive PPE programme for both routine maintenance and emergency scenarios. • Required PPE includes helmets, gloves, arc-resistant clothing, boots, and lifting aids for handling heavy modules. • Tailor PPE requirements for specific risks, such as high-voltage exposure or thermal runaway events. • Integrate PPE systems into emergency response plans to ensure readiness. • Follow NFPA 70E and ISO 45001 for PPE standards.

5. List of Standards

Note: This list is not exhaustive; it includes only the standards explicitly mentioned in this document. Additional standards may be relevant depending on specific applications and regulatory requirements.

International Standards

CSA Z462 – Workplace electrical safety standard.

IEC 62933-5-1 / 2 / 3 – Safety standards for energy storage systems.

IEC 62485-5 – Safety requirements for secondary batteries.

IEC 62619 – Safety requirements for secondary lithium-ion cells and batteries for industrial applications.

IEC 63056 – Safety standard for lithium-ion battery systems.

IEC 60529 – Degrees of protection provided by enclosures (IP Code).

IEEE C57.12 – Standard for power transformers.

NFPA 70 – National Electrical Code (NEC).

NFPA 855 – Standard for the Installation of Stationary Energy Storage Systems.

NFPA 68 – Standard on Explosion Protection by Deflagration Venting.

NFPA 69 – Standard on Explosion Prevention Systems.

OSHA 1910.269 – Safety standards for electric power generation.

UL 9540/A / 1973 / 1974 – Safety standards for battery energy storage systems and lithium-ion batteries.

European Standards

EN 54 – Fire detection and alarm systems.

EN ISO 11612 – Protective clothing for heat and flame.

Regulation (EU) 2023/1542 – Battery safety requirements.[35]

Other Relevant Standards

ISO 13849 – Safety of machinery.

ISO 26262 – Functional safety for road vehicles.

[35] This is not a standard, but relevant to mention.

ISO 22320 – Emergency management guidelines.

ISO 45001 – Occupational health and safety management systems.

ISO 50001 / 55000 – Energy and asset management standards.

UN 3536 – Lithium batteries in cargo transport units.

OECD Guidelines – Chemical impact testing.

6. Appendix

Lightning And Overvoltage Battery Storage Protection – Analysis of the Risk of Lightning Damage and Losses of Energy Storage Facilities

Lightning discharges pose a direct and indirect threat to devices used for generating, processing and storing electrical energy. Facilities containing energy storage should be built and designed in accordance with the standards.

The level of lightning and surge hazard caused by BESS depends on their location. BESS can be divided according to their size (domestic and industrial) and the technologies used in them. According to the requirements set by IEC 62305-2 standard, a risk analysis should be carried out and based on it, it should be determined what measures should be taken, what technical solutions should be used, what safeguards should be used to reduce the risk to an acceptable level for the entire facility where the energy storage is installed. Required level of lightning protection depending on the type of energy storage:

Home energy storage	Industrial energy storage	Large-scale energy storage
• Protection class coordinated with the building to which the warehouse is attached. • No worse than 3rd class LPS.	• No worse than 3rd class LPS. • Object with ex zones – no worse than LPS class 2.	• No worse than 2nd class LPS. • Critical infrastructure – 1st class LPS, separated LPS.

Buildings and other facilities where a BESS facility is planned to be located should be protected against the effects of direct lightning discharges by installing a lightning protection system in accordance with the requirements of the IEC 62305 series of standards. The lack of such an installation may cause uncontrolled lightning current flow. The surge current occurring in electrical installations during a lightning discharge may result in the initiation of the thermal runaway phenomenon) by directly damaging the energy storage BMS. Under no circumstances should this uncontrolled process be allowed to occur.

Regardless of the location of the energy storage device, it should be protected against surges in accordance with the requirements of the following standards: IEC 62305-4, IEC 61643-12, IEC 60364-1, IEC 60364-8-2, IEC 60364-5-53 by installing dedicated surge arresters:

a) at the point of connection of the energy storage with the electricity grid,
b) at the point of connection of the energy storage facility with a telecommunications network or another network connected to the storage facility by cable,
c) in the case of large energy storage facilities, if the distance between the modules is greater than 10 meters, another set of surge arresters should be installed in accordance with the above-mentioned sub-items.

The surge arresters used should be certified for compliance with the requirements of the IEC 61643-11, IEC 61643-21 standards (in the near future also IEC 61643-41) and mutually coordinated energetically in accordance with the IEC 61643-12 standard.

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The European Association for Storage of Energy (EASE) is the leading member - supported association representing organisations active across the entire energy storage value chain. EASE supports the deployment of energy storage to further the cost-effective transition to a resilient, carbon-neutral, and secure energy system. Together, EASE members have significant expertise across all major storage technologies and applications. This allows us to generate new ideas and policy recommendations that are essential to build a regulatory framework that is supportive of storage.

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