

INTERNATIONAL STANDARD

NORME INTERNATIONALE

**Electrical energy storage (EES) systems –
Part 5-2: Safety requirements for grid-integrated EES systems –
Electrochemical-based systems**

**Systèmes de stockage de l'énergie électrique (EES) –
Partie 5-2: Exigences de sécurité pour les systèmes EES intégrés dans un
réseau – Systèmes électrochimiques**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –**Part 5-2: Safety requirements for grid-integrated EES systems –
Electrochemical-based systems**

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International Standard IEC 62933-5-2 has been prepared by IEC technical committee 120: Electrical Energy Storage (EES) Systems.

This International Standard is to be used in conjunction with IEC TS 62933-5-1:2017.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
120/173/FDIS	120/182/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62933 series, published under the general title *Electrical energy storage (EES) systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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INTRODUCTION

All the electrical energy storage systems (EESS) follow the general safety requirements as described in IEC TS 62933-5-1, which is based on a systems approach. IEC 62933-5-2 follows the same structure as IEC TS 62933-5-1 and provides additional requirements for battery energy storage systems (BESS). The additional requirements are provided for the following reasons:

- a) BESS can be integrated into a significant range of electrical grids.
- b) The level of safety requirements awareness can vary between utilities, system integrators, operators and end-users.
- c) Although the safety of individual subsystems is generally covered by international standards at ISO and IEC levels, the safety matters that arise due to the combination of electrochemical accumulation subsystems and any electrical subsystems are not always considered. BESS are complex at the systems level due to the variety of potential battery options and configurations, including the combination of subsystems (e.g. control systems for electrochemical accumulation subsystems, electrochemical accumulation subsystems, power conversion subsystems and auxiliary subsystems). Compliance with standards and related material produced specifically for the safety of subsystems cannot be sufficient to reach an acceptable level of safety for the overall system.
- d) BESS can have additional safety hazards, due, for example, to the presence of chemicals, the emission of toxic gases, chemicals spilt around the electrochemical accumulation subsystems and to events critical for safety from electrochemical accumulation subsystems that cause safety issues for the entire BESS. They can cause loss of power at any part of the systems and buildings that can result in additional threats to safety. From a systems perspective, these individual hazards can have a system wide impact.

ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –

Part 5-2: Safety requirements for grid-integrated EES systems – Electrochemical-based systems

1 Scope

This part of IEC 62933 primarily describes safety aspects for people and, where appropriate, safety matters related to the surroundings and living beings for grid-connected energy storage systems where an electrochemical storage subsystem is used.

This safety standard is applicable to the entire life cycle of BESS (from design to end of service life management).

This document provides further safety provisions that arise due to the use of an electrochemical storage subsystem (e.g. battery system) in energy storage systems that are beyond the general safety considerations described in IEC TS 62933-5-1.

This document specifies the safety requirements of an “electrochemical” energy storage system as a “system” to reduce the risk of harm or damage caused by the hazards of an electrochemical energy storage system due to interactions between the subsystems as presently understood.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitute requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2-52, *Environmental testing – Part 2-52: Tests – Test Kb: Salt mist, cyclic (sodium chloride solution)*

IEC 60079-7:2015, *Explosive atmospheres – Part 7: Equipment protection by increased safety “e”*
IEC 60079-7:2015/AMD1:2017

IEC 60079-13, *Explosive atmospheres – Part 13: Equipment protection by pressurized room “p” and artificially ventilated room “v”*

IEC 60079-29 (all parts), *Explosive atmospheres – Gas detectors*

IEC 60364 (all parts), *Low-voltage electrical installations*

IEC 60364-4-44, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-6:2016, *Low voltage electrical installations – Part 6: Verification*

IEC 60529, *Degrees of protection provided by enclosures (IP Code)*

IEC 60664-1:2007, *Insulation coordination for equipment within low-voltage systems – Part 1: Principles, requirements and tests*

IEC 60812, *Failure modes and effects analysis (FMEA and FMECA)*

IEC 61000-1-2, *Electromagnetic compatibility (EMC) – Part 1-2: General – Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena*

IEC 61000-6-7, *Electromagnetic compatibility (EMC) – Part 6-7: Generic standards – Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations*

IEC 61025, *Fault tree analysis (FTA)*

IEC 61660-1, *Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 1: Calculation of short-circuit currents*

IEC 61660-2, *Short-circuit currents in d.c. auxiliary installations in power plants and substations – Part 2: Calculation of effects*

IEC 61882, *Hazard and operability studies (HAZOP studies) – Application guide*

IEC 61936-1:2010, *Power installations exceeding 1 kV a.c. – Part 1: Common rules*
IEC 61936-1:2010/AMD1:2014

IEC 62305-2, *Protection against lightning – Part 2: Risk management*

IEC 62368-1, *Audio/video, information and communication technology equipment – Part 1: Safety requirements*

IEC 62477-1:2012, *Safety requirements for power electronic converter systems and equipment – Part 1: General*
IEC 62477-1:2012/AMD1:2016

IEC 62485-2, *Safety requirements for secondary batteries and battery installations – Part 2: Stationary batteries*

IEC 62619:2017, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for secondary lithium cells and batteries, for use in industrial applications*

IEC 62933-1, *Electrical energy storage (EES) systems – Part 1: Vocabulary*

IEC TS 62933-5-1:2017, *Electrical energy storage (EES) systems – Part 5-1: Safety considerations for grid integrated EES systems – General specification*

ISO/IEC Guide 51:2014, *Safety aspects – Guidelines for their inclusion in standards*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62933-1, IEC TS 62933-5-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

NOTE Where differences in definitions appearing in IEC 62933-1 and IEC TS 62933-5-1 exist, the definition given in IEC 62933-1 prevails, unless otherwise specified here.

3.1

battery energy storage system

BESS

electrical energy storage system with accumulation subsystem based on batteries with secondary cells

Note 1 to entry: The battery energy storage system includes a flow battery energy system (IEC 62932-1:2020, 3.1.15).

Note 2 to entry: Batteries are defined in IEC 60050-482:2004, 482-01-04, and secondary cells are defined in IEC 60050-482:2004, 482-01-03.

3.2

occupied site

location that is within or adjacent to a building or structure with an overhead cover, where people live or work

Note 1 to entry: A location that is not an occupied site is called "unoccupied site".

3.3

type test

conformity test made on one or more items representative of the production

[SOURCE: IEC 60050-151:2001, 151-16-16]

3.4

routine test

conformity test made on each individual item during or after manufacture

[SOURCE: IEC 60050-151:2001, 151-16-17]

3.5

factory acceptance test

FAT

factory activity to demonstrate that the EES system, subsystems, components and additionally supplied systems/devices are in accordance with the specifications

[SOURCE: IEC 62381:2012, 3.1.3, modified – Original definition has been particularized for the ESS system.]

3.6

site acceptance test

SAT

on site activity to demonstrate that the EES system can operate in accordance with the applicable system specifications and installation instructions

[SOURCE: IEC 62381:2012, 3.1.4, modified – Original definition has been particularized for the ESS system.]

4 Basic guidelines for safety of BESS

4.1 General

An assessment and reduction of the risk associated with the BESS as manufactured and as intended to be installed shall be conducted according to the sequence shown in Figure 1.

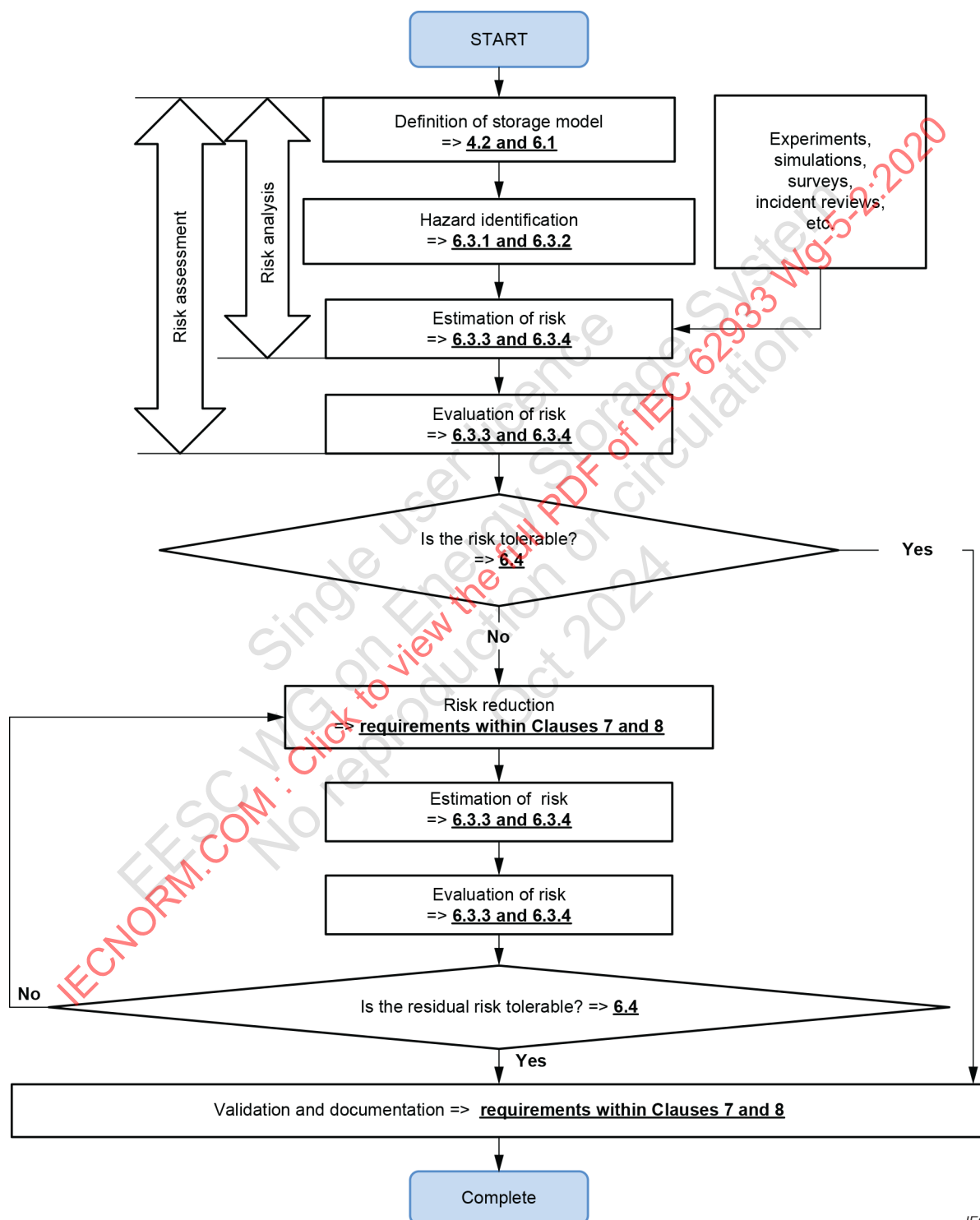


Figure 1 – General description for risk assessment and reduction of BESS

Risks can depend on many factors including location, chemistry and the size/scale (e.g. power) of the BESS and will need to be assessed accordingly. The location of BESS can range from single domestic situations, commercial and industrial applications, to utility scale systems; risks need to be assessed accordingly. Selection of chemistry for the electrochemical accumulation subsystem of the BESS can depend on their environment, performance characteristics and any associated costs and benefits.

As described in ISO/IEC Guide 51, risk reduction measures taken during design are "inherently safe design", "guards and protective devices", and "information for end users". Additional measures at the use phase (life cycle safety management) are also described in ISO/IEC Guide 51.

4.2 Approach to BESS safety

The design of the BESS and its intended installation and integration with the built environment shall accommodate the specific risks that arise during each phase of the BESS life cycle. These life cycle phases typically include, but are not limited to:

- manufacturing/final assembly and factory acceptance testing (see 7.10, 7.11, and 8.2);
- transport (see 7.10, 7.11, and 8.2);
- installation, commissioning and site acceptance testing (see 7.10, 7.11, 7.12 and 8.2);
- operation (see 7.13);
- maintenance and repair (see 7.13);
- repurposing or decommissioning (see 7.13).

During the installation process, soundness of communication among subsystems which are critical to minimizing risk and facilitating incident response shall be ensured to avoid any malfunctions of the protection subsystems. After the installation of the BESS, these subsystems shall be verified by inspection or other suitable means so that their proper functions are assured before the BESS is placed into service.

All health, safety and environment (HSE) requirements applicable to the BESS as installed shall be satisfied during system maintenance and repair.

The safety design considerations and risk analyses for each identified life cycle phase shall be documented and supplied in accordance with Clause 6 and 7.13.

A BESS that is designed and constructed to provide a specified level of reliability and durability shall include not only the levels of safety as a design feature of the overall system but also the subsystem safety level which is necessary to achieve the specified level. At the subsystem level, all integrated electrochemical energy storage subsystems shall comply with appropriate safety standards (e.g. IEC 62477-1, IEC 62619).

Safety measures for interactions between subsystems shall be consistent with the result of the system level safety risk assessment.

Commonly used electrochemical-based BESS POC (point of connection) voltages, energy capacity, site occupancy and chemistry of electrochemical accumulation subsystems are distinguished as listed in Table 1.

Detailed implementation of safety measures required in Clauses 7 and 8 can be optimized in accordance with the result of the system risk assessment of BESS (see Clause 6) using the basic conditions in Table 1.

NOTE 1 Chemistries that are not in common widespread use for stationary applications are not considered in this document but can be considered in future editions

NOTE 2 "Energy capacity" of BESS" means the total energy capacity of electrochemical accumulation subsystems which are equipped behind one POC.

Table 1 – BESS categories

Features for categorization	Category denominations	Explanation
"POC voltage" where BESS is connected	V-L	Low: $V \leq 1 \text{ kV AC or } 1,5 \text{ kV DC}$
	V-H	High: $V > 1 \text{ kV AC or } 1,5 \text{ kV DC}$
"Energy capacity" of BESS	E-S	Small: $E \leq 20 \text{ kWh}$
	E-L	Not small: $E > 20 \text{ kWh}$
"Site occupancy" in relation to electrochemical accumulation subsystem	S-O	Occupied site (see 3.2)
	S-U	Unoccupied site (see 3.2)
"Chemistry" of electrochemical accumulation subsystem	C-A	BESS using non-aqueous electrolyte battery (e.g. Li-based)
	C-B	BESS using aqueous electrolyte battery (e.g. Lead acid, Ni-based)
	C-C	BESS using high temperature battery (e.g. NaS, NaNiCl)
	C-D	BESS using flow battery
	C-Z	Others
NOTE 1 Denominations of BESS categorization are described as "V-X / E-X / S-X / C-X" in any requirements of this document (e.g. V-H / E-L / S-U / C-C). Some characteristics can be omitted if any limitation of category does not apply. NOTE 2 To apply this document to both BESS and other electrochemical-based EESS including chemical based supercapacitors, the latter EESS are included in category "C-Z". NOTE 3 Combinations of two or more electrochemical accumulation chemistries are included in category "C-Z".		

Examples of BESS use can be described as shown in Table 2.

Table 2 – Examples of BESS use

Use scene	Site	Access restrictions/conditions during operation and maintenance
Residential	Installed in individual homes or shared by a small number of homes and a large number of apartments buildings or villas.	Can be placed in a location that is not accessible for regular maintenance without cooperation of the inhabitants of the home and is not part of a professional operating and maintenance regime.
	An example of using Table 1 in this BESS use scene can be as follows: "V-L/E-S or L/S-O or U/C-A or B".	
Commercial	Installed in small businesses, shared by a large number of homes, or a mixture of the above uses such as a street or an apartment building.	Placed in a location that is accessible for regular maintenance during business hours and is usually part of a professional operating and maintenance regime.
	An example of using Table 1 in this BESS use scene can be as follows: "V-H or L/E-L/S-O or U/C-A, B, C or D".	
Industrial	Installed in large businesses such as factories, data centers, warehouses etc., or shared by a large number of homes, such as a city quarter.	Placed in a location that is accessible for regular maintenance during business hours and is part of a professional operating and maintenance regime.
	An example of using Table 1 in this BESS use scene can be as follows: "V-H/E-L/S-O or U/C-A, B, C or D".	
Utility	Connected directly to the utility grid.	Placed in a location that is continuously accessible for regular maintenance and is part of a professional operating and maintenance regime. The system is typically placed inside a restricted access area, or access to the system itself is restricted to authorized people.
	An example of using Table 1 in this BESS use scene can be as follows: "V-H/E-L/S-O or U/C-A, B, C or D".	

4.3 BESS changes in ownership, control or use

In all cases where a transfer of ownership or operational responsibility occurs, the monitoring log information should be transferred to the new owner as part of the system documentation, including measures for complying with the requirements in 7.13.2 and 7.13.3. When it is necessary to control identified BESS risks, there should be clarification on the roles and responsibilities for managing and controlling any existing or new safety risks arising out of the changes that are planned or have taken place.

Annex A provides further information regarding ownership of BESS.

5 Hazard considerations

The general hazard considerations for EESS in IEC TS 62933-5-1:2017, Clause 5, are applicable.

6 BESS system risk assessment

6.1 BESS structure

6.1.1 General characteristics

A storage model of the BESS shall be created for appropriate safety risk assessment with clarifying features as shown below.

An example of a BESS including a primary POC, auxiliary POC and control subsystem is shown in Figure 2 and Table 2. In some cases, it is possible that one or more subsystems or components are not present. The communication arrangements between management, communication, protection and the other subsystems are shown as dotted arrow lines.

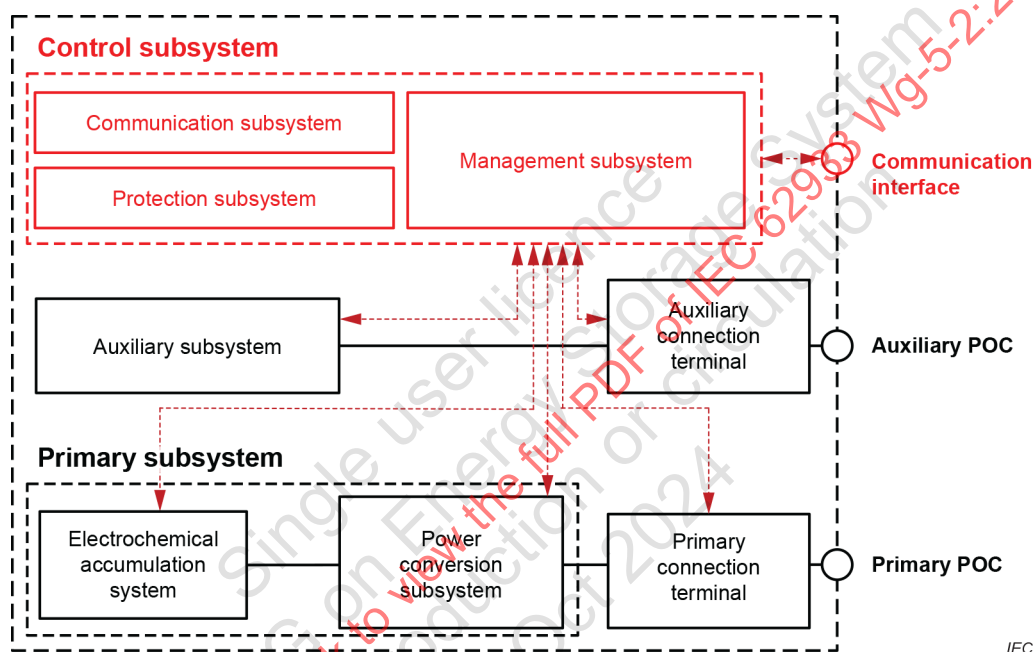


Figure 2 – An example of BESS architecture

NOTE Figure 2 is an example and shows a typical BESS architecture. There can be cases which do not fit in Figure 2.

Table 3 – Examples of components within subsystems of a BESS

"Subsystems"	"Components"
Management subsystem	System controller and/or energy management system
Communication subsystem	Operation panel (human interface), system communication and/or monitoring, meter communication
Protection subsystem	Relays (earth, overcurrent, over-voltage, under-voltage, over-frequency, under-frequency, etc.)
Auxiliary subsystem	Fire, heat, and/or smoke detection system(s), fire suppression system, fire extinguisher, HVAC (heating, ventilation and air conditioning), system anchors, auxiliary transformers, auxiliary power distribution switchgear, auxiliary power uninterruptible power supply (UPS)
Auxiliary connection terminal	Connection terminals, cable (type, fire rating, thermal rating, chemical rating, size and flexibility)
Electrochemical accumulation subsystem	Battery (incl. battery management system), communication devices, protective devices, mechanical fixing, cables NOTE There are many cases where BESS include multiple numbers or types of electrochemical accumulation subsystems
Power conversion subsystem	Transformer, AC/DC converter, inverter, PCS controller, switches
Primary connection terminal	Connection terminal, cable (type, thermal rating, chemical rating, size and flexibility)
Others	Room and/or building/enclosure, foundation, water supply, HVAC system of the building, fuses, safety markings

6.1.2 Specific characteristics

The main types of BESS that have been previously categorized according to 4.2 can differ not only in the chemistry of the electrochemical accumulation subsystem but also according to the type of auxiliary subsystems as given below:

- specific auxiliary subsystem of category "C-C" (BESS using high temperature battery)
 - electrochemical accumulation subsystem heating circuit
- specific auxiliary subsystem of category "C-D" (BESS using flow battery)
 - heat exchanger
 - fluid management system (pump, tank, piping, valve. etc)

6.2 Description of BESS conditions

The basic description of BESS conditions shall be categorized in accordance with Table 1 (see 4.2). The more detailed description in accordance with IEC TS 62933-5-1:2017, 6.2, is applicable to BESS.

6.3 Risk analysis

6.3.1 General

A risk analysis (hazard identification and risk estimation) of the BESS shall be carried out in accordance with 4.1, 4.2, 6.3.2, 6.3.3 and 6.3.4.

The general considerations for analysing any risk of EESS are described in IEC TS 62933-5-1.

An iterative approach shall be applied (because several successive applications can reduce the risk and make the best use with available technology). In carrying out this process, it is necessary to consider the safety of the BESS during all the phases of its life cycle.

Useful information about BESS hazards and risks is provided in Annex B.

6.3.2 Hazard identification specific to BESS

The scenario, as a result of BESS risk assessment, shall include specific subsystem failure modes (identified hazards specific to BESS) as starting points for the analysis.

6.3.3 Risk consideration

BESS risk scenarios shall include all interactions between subsystems. Examples of scenarios include but are not limited to:

- propagation from electrochemical accumulation subsystem(s) to others;
- propagation from non-accumulation subsystems;
- simultaneous failures/faults of multiple subsystems;
- loss of subsystem function related to safety.

6.3.4 System level risk analysis

The system level BESS risk shall be assessed at a component, module and final system level. A suitable analysis shall be performed to demonstrate that suitable risk analysis has been carried out at a component, module and final system level.

The general conditions of "system level risk analysis" are described in IEC TS 62933-5-1:2017, 6.3.3.

The system level BESS risk analysis shall be performed based on the risk (BESS size/severity) and complexity of the system using one of the following techniques or an equivalent one:

- bottom-up first principles risk analysis (e.g. failure mode and effect analysis (FMEA): see IEC 60812);
- top-down analysis (e.g. fault tree analysis (FTA): see IEC 61025);
- combined and/or integrated analysis (e.g. hazard and operability study (HAZOP): see IEC 61882, STAMP (systems theoretic accident model and processes)).

6.4 System level risk assessment

All risks shall be assessed for their impact on operators, users and neighbours who may occupy the site of BESS, and graded as tolerable or not.

NOTE If the systems are reliant upon electronics and software, an evaluation of the functionality of these controls would be conducted. A suitable functional safety standard for example, can be utilized for this purpose.

If some risks are not tolerable, appropriate measures shall be taken, according to the requirements in Clauses 7 and 8.

Documentation attached to the assessment and reduction of risk of the BESS shall be available and shall comprise all requirements specified in Clause 6.

7 Requirements necessary to reduce risks

7.1 General measures to reduce risks

The general safety considerations for an EESS are described in IEC TS 62933-5-1:2017, 7.1.

The priority of risk reduction approaches (from ISO/IEC Guide 51:2014, 6.3.5) shall be:

- a) inherently safe design;
- b) guards and protective devices;

c) information for end users.

Inherently safe design measures are the first and most important step in the risk reduction process. This is because protective measures inherent to the characteristics of the product or system are likely to remain effective, whereas experience has shown that even well-designed guards and protective devices can fail or be violated, and information for use might not be followed.

Guards and protective devices shall be used whenever an inherently safe design measure does not reasonably make it possible either to remove hazards or to sufficiently reduce risks. Complementary protective measures involving additional equipment (e.g. emergency stop equipment) might have to be implemented.

The end user has a role to play in the risk reduction procedure by complying with the information provided by the designer/supplier. However, information for use shall not be a substitute for the correct application of inherently safe design measures, guards or complementary protective measures.

All the safety design measures required in 7.2 to 7.12 shall be considered in accordance with BESS risk assessment processes specified in Clause 6.

NOTE Some of the specified measures can be waived provided that clear demonstration is made in the risk assessment that safety objectives supported by the waived measures are clearly achieved, even without the implementation of the concerned measure.

7.2 Preventive measures against damage to neighbouring inhabitants

The general safety considerations of EESS described in IEC TS 62933-5-1:2017, 7.2, are applicable.

7.3 Preventive measures against physical injury or damage to the health of workers and residents

The general safety considerations of EESS described in IEC TS 62933-5-1:2017, 7.3, are applicable.

7.4 Overcurrent protection design

The general safety considerations of EESS described in IEC TS 62933-5-1:2017, 7.4, are applicable.

7.5 BESS disconnection and shutdown

The general safety considerations of EESS described in IEC TS 62933-5-1:2017, 7.5, are applicable. Additional safety requirements necessary to reduce risks of BESS during disconnection and shutdown are described in 7.11.2.

7.6 Operation and maintenance

The general safety considerations of EESS described in IEC TS 62933-5-1:2017, 7.6.

7.7 Staff training

The general safety considerations of EESS described in IEC TS 62933-5-1:2017, 7.7, are applicable.

7.8 Safety design

The general safety considerations of EESS described in IEC TS 62933-5-1:2017, 7.8, are applicable. Additional safety requirements necessary to reduce the risks of BESS through safety design are described in 7.10, 7.11.1, 7.11.3, and 7.12.

7.9 General requirements for BESS safety

Any failure or fault with a subsystem should not be spread outside of the subsystem itself.

Any subsystem that develops a fault which could affect the safe operation of the BESS should be capable of being isolated from other subsystems. The safety functions of subsystems shall not be affected by such isolation and shall operate independently.

The BESS design should minimize noise, vibration and extreme temperatures generated from the BESS.

The architecture of subsystems within the BESS should not prevent operators from recognizing hazardous parts, sections and conditions.

Additionally, for category "V-H" BESS, measures shall be taken for preventing any remote dangerous operations if no evidence can be obtained that no worker is at risk at the site.

Ergonomic principles specified in an appropriate standard (e.g. ISO 9241 (all parts)) should be taken into account in designing machinery so as to reduce the mental or physical stress of, and strain on, the operator. These principles should be considered when allocating functions to operator and machine (degree of automation) in the basic design.

7.10 Inherently safe design of BESS

7.10.1 Protection from electrical hazards

The electrical installation of category "V-L" BESS shall be in accordance with appropriate parts of the IEC 60364 series.

The electrical installation of category "V-H" BESS shall be in accordance with IEC 61936-1 and IEC 60364 (all parts).

The electrical protection for any DC subsystem shall be safe in accordance with IEC 61660-1 and IEC 61660-2.

The live parts of subsystems and the components of BESS that have hazardous voltage (above extra-low voltage (ELV)) circuits shall not be accessible to unauthorized people. The parts of BESS which are likely to cause electric shock shall be securely covered. The conductive parts of BESS which people are likely to touch shall not be connected to any parts at hazardous voltage. The protection can be achieved by one of the following methods:

- preventing a current from passing through the body of any person or any livestock;
- limiting the current which can pass through a body to a non-hazardous value.

The electric wires and insulation shall each be rated for the maximum current, voltage and temperature.

All conductive parts of a BESS which can come in contact with a hazardous voltage through a single insulation fault shall be connected to earth in accordance with appropriate standards, manufacturer instructions and local regulations.

The physical spacing of circuits, including securing leads and terminals, etc., shall be sufficient to prevent inadvertent short-circuits and/or the potential for arc flash.

Connection points of bare conductors shall be appropriately spaced and of suitable structure to prevent inadvertent short-circuits between electrochemical accumulation subsystems.

A risk assessment in accordance with the procedures contained in IEC 62305-2 shall be made to evaluate if lightning protection is needed. If the assessment indicates that protection against lightning is required, then it shall be provided.

The voltage measurement systems associated with the BESS should use a voltage reference.

Safety-related components (for example, certain sensors) of known reliability shall be used.

Protective devices, such as guards, shall be designed to be effective, as their failure can expose persons to hazards, and also because a reduction in their effectiveness could encourage attempts to defeat them.

The touch current and discharge energy shall be limited in accordance with IEC 62477-1:2012, 4.4.3.4.

The BESS shall be provided with an overcurrent protection function at the electrochemical accumulation subsystem connection.

Duplication (or redundancy) of components may be used so that, if one component fails, another component or components continue to perform the respective function(s), thereby ensuring that the safety function remains available.

Testing shall be conducted, and compliance shall be assessed in accordance with 8.2.1.3, 8.2.1.4, 8.2.1.5, and 8.2.1.6.

7.10.2 Protection from mechanical hazards

The components which people are likely to touch shall not have sharp edges.

Where edges or corners could be hazardous to personnel depending on the location or application in the equipment, they shall be rounded or smoothed.

Hazardous moving parts of the equipment (which means moving parts that have the potential to cause injury) shall be so arranged, enclosed or guarded as to reduce the risk of injury to persons.

The structure of the BESS shall have adequate protection and reduce the risk of subsystems and components dropping during operating conditions, transportation, assembly, installation and disassembly.

The BESS shall be designed to keep operators and workers safe in normal operation.

The location and structure of the BESS shall be such as to not cause risks to workers in the event of component malfunction.

Failure of interconnections between BESS subsystems shall not lead to a hazardous situation.

The BESS shall be designed and installed to allow the installation and removal of battery modules using appropriate lifting equipment, unless the weight of the individual modules is low enough to be safely handled by at most two people.

Validation shall be conducted, and compliance shall be assessed, in accordance 8.2.2.1, 8.2.2.2 and 8.2.2.3.

7.10.3 Protection from explosion

Flammable materials shall not be placed in the path of gas or heat exhaust from electrochemical accumulation subsystems.

Control subsystems and those components placed in any explosive atmospheres shall be provided with a suitable gas purging system in accordance with appropriate standards, manufacturer instructions and local regulations.

A BESS enclosure or compartment shall not vent any flammable gases into any enclosed spaces where arc-producing elements are located.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.3.1, 8.2.3.2 and 8.2.3.3.

7.10.4 Protection from hazards arising from electric, magnetic, and electromagnetic fields

Safety functions of safety-related subsystems of BESS shall not be disturbed by electric, magnetic, and electromagnetic fields.

Where expected electric, magnetic, and electromagnetic noise levels could have an adverse impact on the operation of the BESS, the BESS shall be adequately protected to reduce those noise levels within the system manufacturer's instructions.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.4.

7.10.5 Protection from fire hazards

Only non-combustible materials shall be used in the construction of the BESS enclosure or supporting structures and assemblies.

NOTE The non-combustibility test is described in ISO 1182.

Integration of electrochemical accumulation subsystems and their surroundings shall be designed to prevent chains of thermochemical reactions or fire propagation (e.g. separating into a battery section, charging equipment section and a section which includes a DC conductor, circuit breaker and discharge circuit). Where applicable, both fire and thermal risks that are adjacent to the BESS shall also be considered.

Compliance shall be reviewed by conducting safety design checks in accordance with the result of system level risk assessments (see Clause 6). Fire-load calculations on the BESS, or the experimental fire characteristics recommended in 8.2.5 with details in Annex C are applicable for the process of system risk assessment.

The inside of the BESS shall be separated into a battery section, charging equipment section and a section which includes a circuit breaker and discharge circuit, using fire-proof partitions (e.g. metal plates, non-flammable boards, etc.).

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.5.

7.10.6 Protection from temperature hazards

The components that have the potential to be at high temperature shall not be accessible to operators or any other personnel. The parts which are likely to cause burns shall be securely covered.

Thermal partition such as a metal plate or appropriate physical spacing shall be provided between the electrochemical accumulation subsystems and the control subsystem.

7.10.7 Protection from chemical effects

The choice of materials used in enclosures and wires of the BESS shall consider degradation, corrosion, wear (due to long-term use) and toxicity in accordance with the system risk analysis performed and local regulations.

Consideration shall be given to adverse long-term changes in electrical and mechanical properties of certain insulating materials.

The effects of electrolyte spillage from the battery shall be prevented. This requirement does not apply to batteries with sealed structures.

The structure of the BESS shall be designed to prevent the scattering of hazardous fluid from electrodes or electrolytes in electrochemical accumulation subsystems in accordance with local regulations.

7.10.8 Protection from hazards arising from auxiliary, control and communication system malfunctions

Equipment shall be so designed that the risk of fire or electric shock due to mechanical or electrical overload or failure, or due to an abnormal operation or careless use, is limited as far as practicable. After an abnormal operation or a single fault, the equipment shall remain safe for an operator within the meaning of this document, but it is not required that the equipment still be in full working order. It is permitted to use fusible links, thermal cut-outs, overcurrent protection or similar devices as long as they are able to provide adequate protection.

BESS shall be designed to prevent a hazardous condition even if the energy supply (from both a primary POC and an auxiliary POC) is interrupted or has fluctuated.

When a safety critical component fails or operates abnormally, the system shall enter a safe state automatically.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.8.

Guidance on conducting single fault conditions on control and other circuits can be found in IEC 62368-1.

Operator safety after an abnormal operation or a single fault should be checked by system testing with suitable simulated signals in accordance with IEC 62368-1.

7.10.9 Protection from hazards arising from environments

7.10.9.1 General

The BESS shall be designed to prevent a hazardous condition even if the BESS is exposed to conditions as given in 7.10.9.2 and 7.10.9.3.

7.10.9.2 Exposure to moisture ingress

The BESS shall be designed to prevent the effect from moisture ingress.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.9.2.

For category “S-U” BESS, a minimum IP code of IPX4 shall be determined in accordance with IEC 60529.

7.10.9.3 Exposure to marine environments

In case of installation in marine environments, the BESS shall be designed so as not to result in hazardous events during or after exposure to marine environments (e.g. salt fog).

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.9.3.

7.11 Guards and protective measures

7.11.1 General

In addition to the inherently safe design of the BESS which is described in 7.10, guards and protective measures shall be used in a BESS. The minimum requirements of the guards and protective measures are given in 7.11.

Access control is integral to safe operation of a BESS, and appropriate locks and restriction to unauthorized personnel access shall be included in the system design. A safety interlock shall be provided where hazards within the context of this document are normally present and operator access involves areas normally presenting hazards within the context of this document.

The battery management system in any electrochemical accumulation subsystem shall monitor all relevant safety parameters of the battery as required in the applicable standards and report those parameters to the control subsystem.

For those BESS located where there is the potential for direct contact by untrained persons, a minimum IP code of IP2X shall be determined in accordance with IEC 60529.

7.11.2 BESS disconnection and shutdown

7.11.2.1 General

In addition to the operational states that are defined in IEC TS 62933-5-1:2017, 7.5, a non-operational condition (the isolated condition for maintenance) is defined in this document. The isolated condition for maintenance is a system condition that allows for safe working on the DC power circuitry and electrochemical accumulation subsystem.

7.11.2.2 Grid disconnected state

The general requirements that are described in IEC TS 62933-5-1 shall apply. Additionally, isolating devices shall be used to allow local manual operation to override remote operation. The isolating devices shall be lockable in the disconnected state.

7.11.2.3 Stopped state

In the stopped state, the system has performed a shutdown sequence which includes the disconnection of the electrochemical accumulation subsystem from the power conversion subsystem, and the disconnection of the power conversion subsystem from the primary connection terminal. The stopped state can result from a regular command, or an emergency shutdown event command. Auxiliary power is still present to facilitate an automatic power-up sequence, or to power monitoring systems. This state is typically achieved using contactors or motorized circuit breakers. During their installation, the possibility of automatic re-energization or insufficient isolation should be minimized for workers on the site.

7.11.2.4 Isolated condition for maintenance

In the isolated condition for maintenance, it should be safe to work on at least the DC power circuit and storage component of the system. The whole isolation of the BESS (see Figure 3) or the partial isolation around the DC side of the BESS may be selected in accordance with the area that should be maintained. The BESS shall be capable of being locked in the isolated condition locally or via a removable disconnection tool so that it can only be connected by authorized personnel after the maintenance procedure. In order to bring the system to an isolated condition, the BESS shall first be brought to the stopped state as defined above. It shall then be capable of being brought and locked into a grid disconnected state, and then it shall be safely isolated (including keeping any power supply for safety-related subsystems of the BESS active). Consideration may be given to providing visible isolation with the lockable isolation device as is required in some jurisdictions.

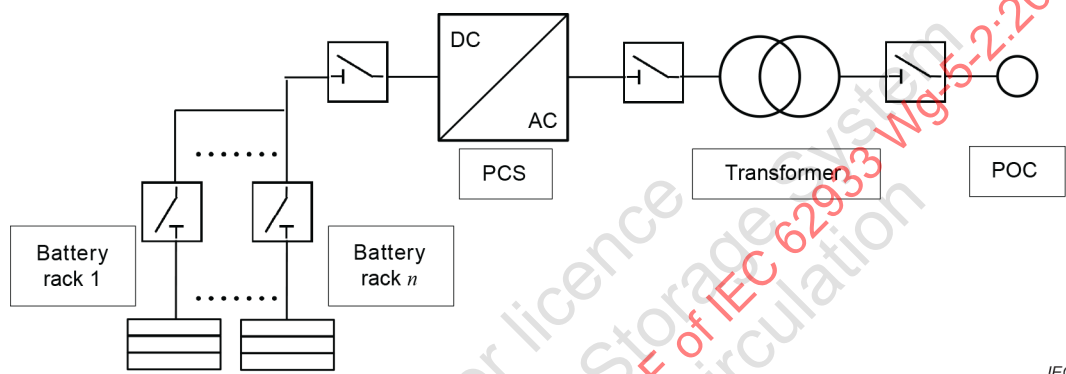


Figure 3 – Example of isolated condition (whole isolation of BESS)

The procedure to isolate the system shall:

- allow for disabling of the fire suppression system where a release of the fire suppression agent can be harmful to people working in or near the system;
- allow the fire detection systems, HVAC, lighting and utility outlets to remain operational in the isolated state, to provide safe and comfortable working conditions.

The instructions to isolate the system shall:

- be permanently attached to the system in a single location that is easily accessible to the person who carries out the system isolation;
- provide clear instructions and checks to achieve and confirm full isolation of the system;
- provide clear instructions for restoring the system back to the operational (stopped) state.

The individual isolating devices referred to by the instructions shall be clearly marked.

7.11.3 Other guards and protective functions of BESS

7.11.3.1 Protection from electrical hazards

Protective devices and electric circuits shall be properly rated to protect electric circuits against short-circuits.

Electrochemical accumulation subsystems (within the energy storage) shall be provided with a protective function to stop or limit short-circuit currents.

Earth fault protection shall be kept within both the AC and the DC sides of the power conversion subsystem. Detection of an earth fault shall be reported to operators. This protection is mandatory if the AC and DC side are electrically isolated from a distribution grid. DC side protection is not necessary for safety extra-low voltage (SELV) battery voltage.

The BESS shall protect the batteries against overcharge and impulse voltage, including under a single fault condition within the charger. Protection can be accomplished by turning off the charger, or by interrupting the charging current or varistor. If an overcharge happens, it shall be reported (to operators) by both audible alerts and visual signals.

The complete rating of a replaceable fuse should be marked on the fuse holder or adjacent to the fuse holder so that the rating of a fuse is obvious even if the fuse is removed. Other necessary information such as I^2t time delay or breaking capacity shall be indicated with the rating. The fuse replacement procedure shall be described in the BESS information described by the safety design and functions set out in 7.12.

Overcurrent conditions in electrochemical accumulation subsystems shall be reported to operators.

Limited current circuits shall be so designed that the limits are not exceeded under normal operating conditions and in the event of a single failure within the equipment. If an overcurrent happens, it shall be reported to operators.

Unintentional islanding of BESS should be considered in accordance with IEC TS 62933-5-1:2017, 6.2.8.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.1.1 and 8.2.1.2.

7.11.3.2 Protection from mechanical hazards

BESS enclosures that provide protection from access to hazardous parts shall be sufficiently robust to prevent mechanical damage due to possible mechanical abuse.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.2.1 and 8.2.2.2.

7.11.3.3 Protection from explosion

In conditions of category "V-L/S-O/C-A, C-B, C-D and C-Z", detection systems for flammable gases generated by the electrochemical accumulation subsystems shall be provided at the site where the BESS is located. When a flammable gas is detected, it shall be reported (to operators) by both audible alerts and visual signals. It is a requirement of this document that the BESS cannot be installed in the site without any detection systems for flammable gases and that this requirement shall be contained in the installation manuals.

Category "V-L/S-U/C-A, C-B, C-D and C-Z" BESS shall have appropriate signage to identify restricted areas. The sign shall specify that flammable gases can be released from the BESS.

Category "V-H/S-O/C-A, C-B, C-D and C-Z" BESS themselves shall be provided with detection systems for flammable gases generated by electrochemical accumulation subsystems. An incident of flammable gas detection shall be reported (to operators) by both audible alerts and visual signals. The handling procedure of the detection systems shall be described in the system documentation as described in 7.12.

In category "V-H/S-U/C-A, C-B, C-D and C-Z" BESS, the path of exhausted flammable gases shall be identified and documented in the installation manual. Appropriate signage to identify a restricted area shall be provided around any flammable gas outlet. Information of the path of the exhausted flammable gases shall be provided by the supplier to the owner.

In category "C-A, C-B, C-D and C-Z" BESS, electrochemical accumulation subsystems can exhaust hydrogen. To prevent explosion or fire, the BESS shall not have any ignition sources where the density of hydrogen can be over 4 % (lower explosion limit of hydrogen) at the time of any incidents.

For category "V-H/C-A, C-B, C-D and C-Z" BESS, appropriate reliable and/or redundant means to avoid flammable gas build-up inside the BESS shall be implemented.

Category "V-L/S-O/C-A, C-B, C-D and C-Z" BESS shall be located in the site with appropriate ventilation systems.

Category "V-H/S-O/C-A, C-B, C-D and C-Z" BESS shall be installed with appropriate ventilation systems as provided for in the following:

- the ventilation systems shall be able to keep an appropriate temperature within the enclosure,
- forced ventilation systems shall be provided where there is insufficient natural ventilation,
- the ventilation openings shall be designed and installed to prevent the spread of fires and water ingress.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.3.1, 8.2.3.2 and 8.2.3.3.

7.11.3.4 Protection from fire hazards

A risk of fire can result from excessive temperatures either under normal operating conditions or due to overload, component failure, insulation breakdown or loose connections. Fires originating within the equipment should not spread beyond the immediate vicinity of the source of the fire, nor cause damage to the surroundings or the equipment.

Category "S-O" BESS shall have a fire detection system, fire alarms deploying both audible alerts and visual signals, and fire extinguishers within the BESS location.

For category "S-O" BESS, if the electrochemical accumulation subsystems of the BESS have doors, the doors shall be fire-protecting doors.

Category "S-U" BESS shall have a fire detection system, fire alarms deploying both audible alerts and visual signals, and fire extinguishers within a safe and easily accessible location.

A signal of fire detection sent from the fire detection system shall be transmitted to the fire alarms with location data via a communication network and fire suppression system, or via secure relays and receivers where applicable.

If a fire incident is detected, the fire suppression system, if any, shall automatically operate and the fire alarms shall be automatically started.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.5.

7.11.3.5 Protection from temperature hazards

The BESS can have one or more critical temperatures which should be identified. According to the identified critical temperatures (e.g. touchable surface temperatures, power electronic component temperatures, and electrochemical accumulation subsystem temperatures), safety provisions shall be implemented to prevent these temperatures from being reached within the BESS.

Safety-related components (for example, certain sensors) of known reliability shall be used.

It shall be possible for operators to monitor the temperatures of the internal atmosphere of a system enclosure.

It shall be possible for operators to monitor the temperatures of subsystems in the BESS.

It shall be possible for operators to monitor operating conditions of ventilation subsystems, and detection of abnormal conditions shall be reported to operators.

When the monitored temperature(s) exceed(s) the(those) limit(s) provided by the manufacturer, it shall be reported to operators.

Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.6.1, 8.2.6.2 and 8.2.6.3.

7.11.3.6 Protection from chemical effects

Containment and/or neutralization of spilt hazardous fluids shall be provided. Methods utilized for containment shall be sufficient to hold the maximum quantity of fluids that could occur and if located outdoors designed to prevent inadvertent filling with rain. Instructions regarding the provision of suitable spill containment and neutralization shall be provided by the system manufacturer with the installation instructions.

For category "C-D" BESS, an automatic leak detection to indicate the release of hazardous fluids shall be provided.

For category "E-S/S-O" BESS, a detection system for toxic gases generated by electrochemical accumulation subsystems shall be provided on the BESS site. An incident of toxic gas detection shall be reported (to operators) by both audible alerts and visual signals. Installation manuals shall include a statement that the BESS cannot be installed in the site without toxic gases detection systems.

For category "E-S/S-U" BESS, appropriate signage to indicate a restricted area shall be provided at the site where the BESS is located or on the BESS itself. The sign shall specify that toxic gases can be released from the BESS.

For category "E-L/S-O" BESS, a detection system for toxic gases generated by electrochemical accumulation subsystems shall be provided in the BESS. An incident of toxic gas detection shall be reported (to operators) by suitable alerts and signals (e.g. audible and visual). Installation manuals shall include information on how to handle the detection system for toxic gases.

For category "E-L/S-U" BESS, the path of exhausted toxic gases shall be identified and documented in the installation manual. Appropriate signage to identify a restricted area shall be provided around an outlet. Information of the path of exhausted toxic gases shall be provided by the supplier to the owner.

For category "S-O" BESS, gas concentration reduction measures shall be provided in order to protect the work space from the high density of toxic gases from electrochemical accumulation subsystems in the BESS.

Category "E-S/S-O" BESS shall be located in the sites that have protective measures against the hazards above such as, but not limited to:

- elimination of the generation of hazardous chemicals,
- dilution of hazardous chemicals,
- collection of hazardous chemicals (e.g. by a scrubber for hazardous gases),
- limitation of human access.

Category “E-L / S-O” BESS shall be installed with the protective measures described above. Testing shall be conducted, and compliance shall be assessed, in accordance with 8.2.7.1, 8.2.7.2, and 8.2.7.3.

7.12 Information for end users

Safety information as listed below should be available for end users:

- Warning signs and signals (including any limitation of available environments, confirmed by the validation and testing specified in 8.2.9).
- On-site signage and labelling which show any hazardous part of the BESS clearly.
- Warning devices (audible alerts and visual signals), or others.
- A sequence diagram of safety designs shall be described via methods as specified in an appropriate international standard (an example of a reference document is IEC 60617 (all parts)).
- All the BESS information about the safety design and functions shall be kept accessible and available to all applicable BESS stakeholders.

For rooms of electrochemical accumulation subsystems, appropriate information on the required flow of air shall be provided in the installation instructions where the electrochemical accumulation subsystem installation is supplied with the BESS. See Annex F for good practice for warning signs regarding BESS safety.

Any other necessary information shall be provided in accordance with local regulations.

7.13 Life cycle safety management

7.13.1 Operation and maintenance

7.13.1.1 General

Any party which has responsibility for operations and maintenance should be mindful of their own safety when they work near the BESS. Incorrect operation and inadequate or neglected maintenance can cause harm by fire, gas poisoning and electric shock. It is necessary for all stakeholders to protect themselves from such risks.

Most BESS are expected to be operated automatically and remotely via information networks. The BESS is expected to be operational for decades. During such time, BESS parts will be replaced at regular scheduled preventive maintenance or as the result of unplanned events, such as the maintenance plan, preventive maintenance, system condition monitoring, partial subsystems or component replacement, or design change due to ageing degradation.

NOTE The replacement will take into account the potential for any secondary use.

The availability of original parts for repair and replacement can be limited, or the parts can be unavailable and compatible parts might be used. From a systems safety perspective, replacement parts shall be confirmed to be safe in the system before replacement because combinations of those parts or subsystems are important for monitoring of the system condition.

Any changes by on-site workers shall not be overwritten by any remote actions during the maintenance process by off-site workers to keep on-site workers safe. Consideration shall be given to adverse long-term changes in the electrical and mechanical properties of certain insulating materials.

7.13.1.2 Operation and maintenance plan

An emergency response plan for safety shall be prepared, which shall include the requirements of 7.13.1.2.

A safety manual shall include at least descriptions of methods to communicate BESS problems, warnings to local firefighting agencies, workers and the surrounding residents, and the correct use of insulated tools.

When adjusting with a screwdriver or a similar tool while under applied voltage, protection against electric shock or energy hazard caused by inadvertent touch to the applied voltage sections shall be provided. Measures shall be taken to ensure that possibility of inadvertent touch to incorrect parts with the tool is considered in the protection design.

An operation and maintenance manual shall be provided to the BESS owner or their designated agent and include but not be limited to:

- a) how to maintain safety during maintenance (including safety instructions and specification of required personal protective equipment (PPE) for the various maintenance operations),
- b) methods to detect, manage and control fire, explosion and toxic gas retention, etc., including possibilities for venting gases outside in an emergency situation,
- c) prohibited operating processes, for example,
 - prohibition of overcharge
 - prohibition of over discharge (to avoid polarity inversion)
 - prohibition of charge or discharge in operating temperature exceeding the limit provided by the manufacturer
- d) emergency contact number(s),
- e) safety issues to be disclosed in public (e.g. restricted area around the BESS),
- f) how to use safety subsystems,
- g) how to use protection subsystems,
- h) locking and unlocking procedures of all the protection subsystems,
- i) the identification and specification of hazardous parts of the BESS.,

NOTE These requirements do not prevent any other necessary safety issues from being described within any manuals and guidelines.

Information concerning the design and the installation processes shall always be accessible and checked during maintenance processes which might include following:

- The BESS components that are operated frequently under automatic and/or remote control.
- Failure and/or malfunctions can be caused by the ingress of soil, overgrowth of plants, filter or clogging up of filter or pipe, etc.
- Cleaning and consumable replacement schedules should be included in the operation and maintenance plan.
- The nature and content of the design or construction safety information that is to be provided to users by the supplier or manufacturer. This shall include but may not be limited to:
 - all subsystem parameters related to safety,
 - combination of subsystems and software that may impact on system safety for equivalent (replacement) devices,
 - past trouble instances, issues and quality problems associated with replacement of devices that may be deemed equivalent,
 - measurement accuracy and the condition of installation of sensors,
 - sensitivity and the condition of installation of gas sensors.

Information concerning the necessity to ensure that the equipment is unlikely to present a hazard within the meaning of this document during the operation specified by the supplier shall be provided to the user.

If it is necessary to take special precautions to avoid the introduction of hazards when operating, installing, servicing, transporting or storing equipment, the necessary instructions shall be made available.

7.13.1.3 Preventive maintenance

A periodic maintenance schedule shall be developed by the manufacturer or system integrator. The periodic maintenance schedule should include consideration of frequency of use, time elapsed, and ambient environment. Maintenance should include the overall system, each subsystem and subsystem devices.

Regular preventive maintenance such as cleaning and consumables replacement with system monitoring is a key component of safety from a systems perspective. Reactive maintenance is also required for occurrences that a scheduled maintenance would not pick up on and that impact system integrity, such as the ingress of water or soil due to unexpected weather conditions, or when animals such as birds or rodents impact the integrity of the system enclosure.

The malfunction and performance degradation of components and/or parts of the system or the subsystems due to long term use should be considered. They can be present without obvious signs. There can be no obvious indications of the malfunctions of the circuit breakers, lights, ventilation fans. For example, circuit breaking functions can fail when cables from both the contacts of the circuit breaker are welded together. The malfunctions of lights and ventilating fans can only be noticeable after their activation. Measuring and monitoring of system soundness as described in 7.13.1.4 shall be considered to increase the safety of BESS.

Safety manuals for operation and maintenance of the BESS required in 7.13.1.2 shall be utilized by workers under the supervision of trained operators and/or maintenance staff.

7.13.1.4 Measuring and monitoring of system condition

Measuring and monitoring of system soundness are essential for preventive and reactive maintenance. Items that form part of the measuring and monitoring of the system soundness test should be based on knowledge gained from past incidents and risk analysis utilizing FTA, FMEA, etc. The detection of malfunctions and performance degradations should be considered. In most cases the BESS are likely to be operated remotely without trained operators. In such cases, the BESS soundness should be remotely monitored.

At least all the parameters that have been found important for system condition, during the risk analysis, shall be measured and monitored, and the logged information shall be made available to the operators (e.g. voltage, current, temperature, state of charge (SOC), etc.).

During operation and after shutdown, it is important to monitor the parameters to understand the condition of the battery from the point of view of safety. For example, there is a possibility of thermal runaway inside batteries even after disconnection from the grid. Remote monitoring of system soundness shall be continued after disconnection.

Monitoring and controlling functions shall be continually maintained to detect the abnormal status of the BESS under automatic and/or remote control.

7.13.1.5 Staff training

For category "E-S" BESS, any requirement of 7.13.1.5 shall apply to the staff training for the service staff of BESS suppliers.

For category "E-L" BESS, any requirement of 7.13.1.5 shall apply to the staff training for the staff of both the BESS suppliers and operators in accordance with the result of the risk assessment process (see Clause 6).

Staff training shall include safety skills and information. At the installation phase, the BESS provider and subsystem manufacturer shall provide the operating and safety manuals to the owner, installer and operator. These manuals shall include a description on permitted operation and a description of prohibited operation.

Training guidelines and manuals should be prepared using information identified in 7.12. This information should be provided by the supplier and include, but not be limited to:

- evacuation procedure;
- evacuation guidance;
- use of a fire extinguisher or, if any, a fire suppression system in the early stage;
- information communication;
- directions for the use of essential protection tools (e.g. protection instrument, protection equipment including personal protective equipment, and the safety data sheets (SDS) of key chemicals of the BESS subsystems);
- how to retain and record knowledge for the prevention of burns and electric shocks;
- protection measures and control logic of the BESS itself;
- operating methods for safety measures;
- locking and unlocking procedures of all the protection subsystems.

The manufacturer shall provide guidance on the competence and authorization level requirements for personnel who operate devices or safety systems. The guidance shall be taken into account for the requirements operators training or authorization to enter restricted areas.

7.13.2 Partial system change

When the system is partially changed, it is essential that the compatibility and conformity of the parts be checked. Validation of compatibility and conformity of the parts to the system should be considered. Any changes that can degrade the safety level of the BESS should be considered. In addition, the case of BESS relocation also could be considered as similar to the features above.

BESS safety shall be reassessed in the following situations:

- When the BESS is moved or reinstalled at another site.
- Changes in the system itself (for example deterioration due to ageing, reinstallation process, decomposition, transportation and assembly), caused by changes to the BESS throughout its service life (i.e. parts and materials for repair); it shall be confirmed that there is no change in BESS safety condition after the changes.
- Changes required as a result of system or component failure or other incident that could impact on the safety and integrity of the BESS.
- Changes in the application of the BESS.
- Changes in the ambient environment that include, but are not limited to: temperature, humidity, building foundations, rainstorm environment, ventilation, anti-fire provision, and the surrounding environment.

Attention shall be paid to:

- a list of user exchangeable parts,
- changes in output and efficiency,
- when a BESS is located where collateral damage can have a big impact (large building, shopping center, etc.) and located where there are severe environmental conditions (significant changes in temperature),
- chemical risks which can result in the deterioration or the damage to the battery caused by transportation should be minimized during relocation and related installations,
- maintenance records should be referred to at each relocation.

7.13.3 Design revision

The BESS is expected to be in operation for many years. During its lifetime, the system will experience changes due to component obsolescence, upgrades or new technology, environmental changes, market changes or regulation changes. Whenever changes take place, the measures for human safety from a system perspective should be revised accordingly. Thus, a review of the safety design shall be conducted not only at the initial design stage, but whenever the design is changed. Risk analysis shall be a core part of the initial safety design and of any redesign.

For a safety plan and program redesign the risk analysis and FMEA should be repeated. However, depending on the level of the changes, only FMEA can need to be conducted on that part of the system where the changes were made and areas on the whole system that are affected.

Figure 4 shows the safety design considerations of BESS when revisions have occurred. Replacement of entire subsystems or any of their components which have been confirmed to appropriate technical standards may have safety risks at a systems level, and cause incompatibilities of capacity and/or usage risks within the overall BESS, which can result in system level hazards. When available, technically identical subsystems or components should be used in priority.

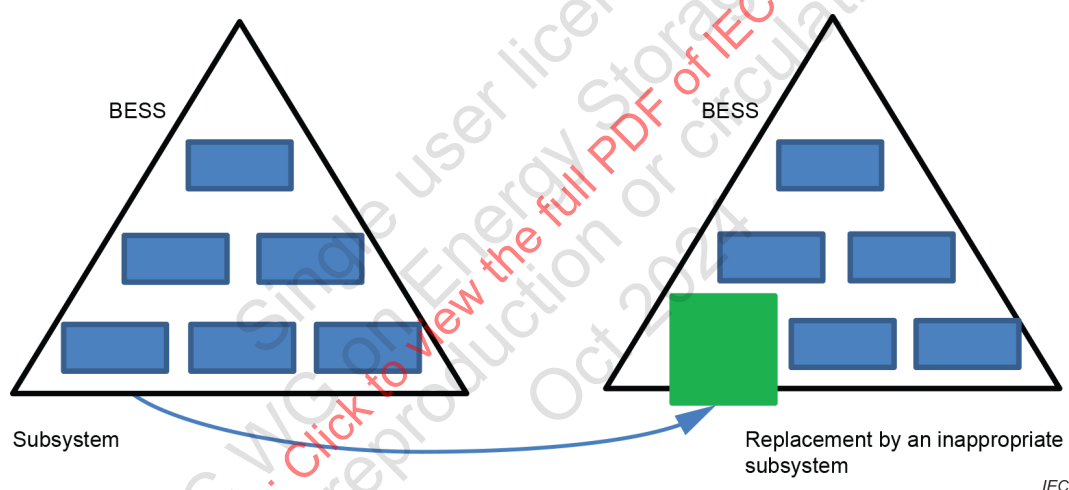


Figure 4 – Incompatibility of capacity and/or usage in a BESS

Examples of incompatibilities that can arise from system changes are listed in Table 4.

Table 4 – Examples of incompatibilities that can arise from system changes

Change	Incompatibility
Electrochemical accumulation subsystem upgrade	Building strength, fire extinguisher, HVAC
PCS upgrade	HVAC, EMC noise tolerance of the other subsystems, etc.
Change of BESS usage (arbitration to frequency) and/or system controller upgrade	Battery, cooling capacity of the other subsystems, etc.

Specifications of ventilation, air conditioning and fire suppression subsystems should be determined considering the fully clarified surrounding environmental difference with respect to relocations.

BESS relocation shall be performed using the same process as that used during initial construction or installation.

7.13.4 End of service life management

The BESS should be designed to be safely dismantled into separate subsystems or into separate components at the end of its life. Dismantled subsystems or components should be handled according to appropriate standards, manufacturer instructions and local regulations.

7.13.5 Measures for validating life cycle safety management

Compliance of 7.13.1 to 7.13.4 shall be confirmed by appropriate validations. Annex E gives information on good practice for these validations.

8 System validation and testing

8.1 General

The BESS testing is conducted to verify the safety and effectiveness of the inherently safe design of the BESS as noted in 7.10 and the guards and protective measures as noted in 7.11. The test program will be impacted by the size (i.e. voltage and amount of energy contained), location of installation (e.g. outdoor remote, indoor), technology (e.g. lead acid), and exposure (e.g. residential). For example, a residential, indoor installation, lithium ion, 240 V, 1 kWh appliance type BESS test program is addressed in a different manner than a large complex utility system consisting of multiple parts that are not a complete BESS until they are installed in the field.

Residential BESS are typically contained in a single mass-produced enclosure and evaluated in the same way as an appliance in that they would be subjected to a type test program, with factory acceptance testing upon production before leaving the factory and perhaps some minor site acceptance testing upon installation. The complex, uniquely designed, utility system would have its major components or subsystems type tested as part of those subsystem standard criteria. The components would be subjected to factory acceptance testing. To evaluate the complete BESS, the site acceptance testing (SAT) would normally need to be more comprehensive, since the BESS is not a complete system until it is assembled and commissioned in the field.

A system type test program should encompass all safety relevant aspects. If system components have already been evaluated according to type test standards by an accredited test house, a re-test of these components as part of a type test is not required.

In addition to the type tests, each individual storage system (or system's major components or subsystems) shall be subjected to a factory acceptance test (FAT) and the complete system shall then be evaluated through site acceptance tests (SAT) after its installation and before being placed into normal operation.

The factory acceptance test (FAT) shall cover at least the following points:

- presence and correct ratings of fuses and breakers;
- presence and correct operation of residual current devices, insulation monitors and earth fault detectors;
- presence and correct operation of automatic and manual disconnectors;
- the system FAT may be performed with a partially installed battery pack or a dummy pack, in case the battery pack components have undergone a separate FAT;
- the system may only be installed on site if one of the following conditions is met:
 - the system passes all tests during the FAT; or
 - the system passes most of the tests from the FAT, and the remaining points can be corrected during installation on-site and re-tested during SAT without negatively affecting the safety situation.

After installation the system is subjected to the site acceptance test (SAT), which shall cover at least the following points:

- a) inspection and resistance measurement of earthing;
- b) correct operation of residual current devices, insulation monitors, earth fault detectors and automatic and manual disconnectors;
- c) correct installation;
- d) testing of any electrical, mechanical and liquid connections made on site;
- e) complete commissioning as per manual, risk analysis and local regulations.

During the SAT, local inspectors, fire brigade officials and government agency representatives may be involved for education, final approval of the system.

The general requirements that are described in IEC TS 62933-5-1:2017, Clause 8, shall apply.

The setting of all interactions between key subsystems of the BESS shall be tested.

Some of the specified system validations and testing may be waived provided that clear demonstration is made in the risk assessment that safety objectives supported by the waived measures are clearly achieved, even without the implementation of the concerned measure.

Table 5 gives an overview of validation and testing of BESS.

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Table 5 – Overview of validation and testing for BESS

Test	Subclause no.	Referenced document	Required tests		
			Type Test	FAT Test	SAT Test
Electrical hazards	8.2.1				
Short-circuit protection	8.2.1.1	-	X	-	-
Overcharge, high current charge and earth fault protection	8.2.1.2	-	X	-	X
Impulse withstand voltage protection	8.2.1.3	IEC 60664-1	X	-	-
Dielectric voltage	8.2.1.4	IEC 60664-1	X	X*	X*
Insulation resistance	8.2.1.5	IEC 60364-6	X	X	X
Earthing and bonding system check	8.2.1.6	IEC 62368-1 IEC 61936-1	X*	-	X*
Anti-islanding	8.2.1.7	-	X*	X*	X*
Mechanical hazards	8.2.2				
Enclosure impact	8.2.2.1	IEC 62477-1	X	-	-
Static force	8.2.2.2	IEC 62477-1	X	-	-
Earthquake impact and vibration	8.2.2.3	-	-	-	X
Explosion	8.2.3				
Specification of flammable gas	8.2.3.1		X	-	-
Gas detection / off-gas detection	8.2.3.2	IEC 60079-29 (all parts)	X	X*	X*
Ventilation	8.2.3.3	IEC 60079-7 IEC 60079-13	-	X*	X*
Hazards arising from electric, magnetic, and electromagnetic fields	8.2.4	IEC 61000-1-2 IEC 61000-6-7 IEC 60364-4-44	X	-	-
Fire hazards (propagations)	8.2.5	IEC 62619	X	X*	X*
Temperature hazards	8.2.6				
Verification of thermal control operation	8.2.6.1	-	X*	-	X
Abnormal operations of subsystems for ventilation	8.2.6.2	-	X	-	X
Temperature under normal operations test	8.2.6.3	-	X	-	X
Chemical effects	8.2.7				
Specification of toxic fluids	8.2.7.1	-	X	-	-
Fluids detection	8.2.7.2	-	X	X*	X*
Protective measures against hazardous fluids	8.2.7.3	-	X	X*	X*
Hazards arising from auxiliary, control and communication system malfunctions	8.2.8	IEC TS 62933-5-1	X	-	X*
Hazards arising from environments	8.2.9				
Resistance to moisture ingress	8.2.9.2	IEC 60529	X	-	-
Exposure to marine environments (salt fog)	8.2.9.3	IEC 60086-5-52	X	-	-
IP rating of BESS enclosure and protective guards	8.2.10	IEC 60529	X	-	-
NOTE 1 The detailed applicable conditions of "X*" testing items can be found in the individual subclauses.					
NOTE 2 Detailed testing items and procedures of SAT can be decided considering the individual BESS system design.					

8.2 Validation and testing of BESS

8.2.1 Electrical hazards

8.2.1.1 High current discharge (short-circuit) protection

The DC circuits of the BESS shall be protected from short-circuits (or be short-circuit proof) on both the AC and DC sides. Each electrochemical accumulation subsystem shall be protected from short-circuit. Each power conversion subsystem shall be protected from short-circuit. Upon application of the suitable simulated signals, the short-circuit protection shall operate to prevent damage to the BESS that can result in a hazardous condition. The short-circuit protection shall operate as designed.

8.2.1.2 Overcharge, high current charge and earth fault protection

Upon installation, the BESS shall be tested with suitable simulated signals to determine whether the charging circuit is disconnected as designed when a state of overcharging, high current charge in electrochemical accumulation subsystems or earth fault in the whole BESS is detected.

Either as a type test FAT check of the protection controls (for category "V-L" BESS) or upon installation as a SAT (for category "V-H" BESS), any subsystem functions providing protection during charging shall be tested during a normal charging operation with suitable simulated signals for the fault events listed below:

- application of each fault, one at a time,
- voltage of the electrochemical accumulation subsystems indicating overcharging,
- current of the electrochemical accumulation subsystems indicating overcurrent, and
- when an earth fault is indicated.

As a result of the applied faults, the BESS overcharge, high rate charge and earth fault protection shall prevent damage to the BESS that would result in a hazardous condition. The protection mechanisms shall operate as designed.

8.2.1.3 Impulse withstand voltage protection

This test is a type test as it can result in damage to the BESS under test. The impulse voltage test is to verify the capability of the solid insulation to withstand the rated impulse voltage. The voltage waveforms used for this test should simulate the overvoltage of atmospheric origin and cover overvoltage due to switching of low-voltage equipment.

An impulse voltage test in accordance with IEC 60664-1:2007, 6.1.3.3, shall be conducted on the BESS.

At least overvoltage category III (for category "V-L" BESS itself) or IV (for safety-related subsystems of category "V-H" BESS) in IEC 60664-1:2007, Table F.1, shall apply for the determination of rated impulse voltages criteria. At least pollution degree 2 or 3 in IEC 60664-1:2007, Table F.2, shall apply for the determination of clearances criteria. As a result of the impulse voltage applications, no puncture or partial breakdown of solid insulation shall occur during the test, but partial discharges are allowed. Partial breakdown will be indicated by a step in the resulting wave shape which will occur earlier in successive impulses. Breakdown on the first impulse can either indicate a complete failure of the insulation system or the operation of overvoltage limiting devices in the equipment.

An impulse test may be waived if the BESS employs surge protection that has already been evaluated for anticipated surges.

8.2.1.4 Dielectric test

The AC dielectric test should verify the capability of the solid insulation to withstand:

- the short-term temporary overvoltage;
- the highest steady-state voltage;
- the recurring peak voltage.

If the peak value of the AC dielectric test voltage is equal to or higher than the rated impulse voltage, the impulse voltage test in 8.2.1.3 is covered by the AC dielectric test.

An AC dielectric test in accordance with IEC 60664-1:2007, 6.1.3.4, shall be conducted. At least overvoltage category III (for category "V-L" BESS itself) or IV (for safety-related subsystems of category "V-H" BESS) in IEC 60664-1:2007, Table F.1, shall apply for the determination of rated impulse voltages criteria. At least pollution degree 2 or 3 in IEC 60664-1:2007, Table F.2, shall apply for the determination of clearances criteria.

As an alternative to the AC dielectric test, a DC dielectric test in accordance with IEC 60664-1:2007, 6.1.3.6, may be conducted.

As a result of the test, there shall be no trace of dielectric breakdown of the tested circuits.

A dielectric test shall also be conducted on the whole BESS or, at least, electrochemical accumulation subsystems with working voltage exceeding ELV as a FAT.

NOTE This test can cause arcing inside battery cells or electrochemical accumulation subsystems with associated ignition and explosion of gases and electrolytes. A safe testing process will therefore be taken.

8.2.1.5 Insulation resistance

An insulation resistance test should be conducted in accordance with IEC 60364-6:2016, 6.4.3.3 and 6.4.3.4.

The resistance of insulation used on hazardous voltage circuits within a BESS shall comply with the values in IEC 60364-6:2016, Table 6.1.

8.2.1.6 Earthing system check

The earthing system of a BESS shall be confirmed in accordance with the methods noted below. The measurements shall be made between any two locations of the earthing system.

For category "V-L", the earthing system of the BESS shall be validated by measurement of the resistance of the earth electrode according to IEC 60364-6:2016, 6.4.3.7.2, or the measurement of the earth fault loop impedance according to IEC 60364-6:2016, 6.4.3.7.3.

For category "V-H", the earthing system of the BESS shall be validated in accordance with IEC 61936-1:2010 and IEC 61936-1:2010/AMD1:2014, Clause 10.

8.2.1.7 Anti-islanding

Any anti-islanding function of the BESS shall be validated or tested in an appropriate way to confirm the requirements in 7.11.3.1.

8.2.2 Mechanical hazards

8.2.2.1 Enclosure strength against impact

For category "E-S" BESS, enclosures shall be subjected to an impact test in accordance with IEC 62477-1:2012, 5.2.2.4.3. As a result of this impact test, there shall be no damage that would result in access to hazardous parts in accordance with 8.2.10. After this test the BESS shall not show any electrical shock hazard as determined in accordance with the dielectric test in 8.2.1.4.

For category "E-L", the enclosure of the subsystems of the BESS shall be subjected to the impact tests as above.

8.2.2.2 Enclosure strength against static force

For category "E-S" BESS, enclosures shall be subjected to the test in IEC 62477-1:2012, 5.2.2.4.2.3. As a result of the force tests, there shall be no damage that would result in access to hazardous parts in accordance with 8.2.10. After this test the BESS shall not show any electrical shock hazard as determined in accordance with the dielectric test in 8.2.1.4.

For category "E-L", the enclosures of the subsystems of the BESS shall be subjected to the force tests as above.

8.2.2.3 Impact and vibration during transportation and seismic events (e.g. earthquakes)

The safety design level against impact and vibration during transportation and seismic events (e.g. earthquakes) generally depends on local regulations and the installation environment. However, the safety level itself should be confirmed on site in accordance with the result of a system risk assessment (see Clause 6). At least the states in the list below shall be verified as SAT in accordance with the standards, manufacturer instructions and local regulations:

- each subsystem and whole system should be securely fixed to structure, foundation or land;
- the power circuits and connection points between subsystems should remain functional after seismic events;
- the control, monitoring and earthing circuits should remain functional after seismic events.

8.2.3 Explosion

8.2.3.1 Specification of flammable gas

Flammable gas which needs to be detected shall be specified during the appropriate system design process.

NOTE This requirement will depend on the electrochemical accumulation subsystem chemistry. As noted in Annex B, some BESS can vent flammable gas under normal operating conditions and other BESS can vent explosive or flammable gas during abuse conditions that result in overheating of the BESS and possible fire or explosion.

8.2.3.2 Gas detection / off-gas detection

Gassing from BESS potentially resulting as a consequence from type tests shall be qualified in terms of flammability characteristics and related risks of explosive atmosphere by appropriate technical means.

NOTE In addition, for BESS that can experience potential for thermal runaway according to Annex B, a large-scale fire test that includes monitoring for flammable gas emissions can need to be conducted. Data on the type and quantity of flammable gas emissions obtained during testing can assist in determining suitable deflagration venting to prevent explosion hazards in the event of a fire from the BESS. See Annex C for details regarding large-scale fire testing.

Upon installation, any functions of the detection systems, audible alerts and visual signals for reporting an incident of flammable gas shall be tested in accordance with appropriate standards, manufacturer instructions and local regulations to confirm that their functions automatically operate when the concentrations of flammable gas exceed the limit which is indicated by the manufacturer. Their functions shall operate as designed. The type test for the individual components of detection systems, audible alerts and visual signals shall be done. The FAT or SAT for the BESS with the combination of detection systems, audible alerts and visual signals shall also be done with suitable simulated signals for events to be detected.

Refer to IEC 60079-29 (all parts) for guidance on flammable gas detectors.

8.2.3.3 Ventilation

The ventilation systems provided at the site where the BESS has been located or provided within the BESS itself shall be tested. The type test for individual components shall be done. The SAT for the BESS with ventilation systems shall also be done. As a result of the tests conducted, the ventilation systems shall automatically operate as designed.

For category "V-H/S-O/C-A, C-B, C-D and C-Z" BESS, and if a forced ventilation system is provided, the SAT for the forced ventilation system shall also be performed with suitable simulated signals which would be sent upon detection of a combustible concentration of flammable gases. As a result of that, the ventilation systems shall automatically operate as designed.

Refer to IEC 60079-7:2015, 6.6.4, for a method to evaluate battery compartment ventilation, or IEC 60079-13.

8.2.4 Hazards arising from electric, magnetic, and electromagnetic fields

The safety functions of the safety-related subsystems of BESS shall comply with IEC 61000-6-7, or functional safety shall be considered with regard to electromagnetic phenomena according to IEC 61000-1-2, if applicable.

Protective measures from disturbance-induced malfunctions of the subsystems of BESS shall be validated with the method given in IEC 60364-4-44.

For category "V-L", compliance with the requirements above shall be confirmed by a type test with a representative BESS.

For category "V-H", compliance with the requirements above shall be confirmed by type tests with individual safety-related BESS subsystems and on-site validation of BESS control subsystems.

8.2.5 Fire hazards (propagation)

Category "C-A" electrochemical accumulation subsystems shall be tested and validated in accordance with the requirements of IEC 62619:2017, 7.3.3.

The fire characteristics of a BESS which has the potential to exhibit thermal runaway according to Annex B should be determined through a large-scale fire test of the BESS that evaluates fire propagation and heat generation for an anticipated BESS installation with and without the fire suppression system. Test data generated as a result of large-scale fire testing can validate a BESS installation with the intended fire suppression system. See Annex C for details regarding large-scale fire testing.

Upon installation, measures below shall be checked:

- for category "S-O" BESS, that fire alarms and fire suppression subsystems are installed and commissioned at the BESS location;

- for category "S-U" BESS, that any fire alarms and fire suppression subsystems are provided within the vicinity;
- in the case of both, if a fire alarm detects a fire hazard, that fire suppression subsystems automatically operate.

In the case that the result of the system level risk assessment shows that a fire suppression system is not needed, it would not be necessary to install a fire suppression system. The effectiveness of the communication function shall be confirmed by inputting suitable simulated signals. The signals shall be transmitted to the communication networks, relays, receivers and fire suppression subsystem securely as designed.

Upon installation, any functions of fire detection systems, audible alerts and visual signals for reporting an incident of fire, and fire extinguishers, shall be tested in accordance with appropriate standards, manufacturer instructions and local regulations to confirm that their functions automatically operate when the fire incident occurs. Their functions shall operate as designed. The type test for individual components of detection systems, audible alerts and visual signals shall be done. The FAT or SAT for the whole of the BESS installation with a combination of detection systems, audible alerts and visual signals, and fire extinguishers shall also be done.

8.2.6 Temperature hazards

8.2.6.1 Verification of thermal control operation

BESS shall be subjected to the following validation or testing:

- Electrochemical accumulation subsystems with battery temperature measurement shall be checked by subjecting them to a suitable simulated signal indicating an over-temperature condition in order to verify the system response.
- When the temperature of the BESS is above specified values, the thermal controls shall stop or otherwise control the charging and discharging to keep the specified operation conditions.
- If not previously conducted as part of the type testing, upon installation, the BESS shall be checked to ascertain if the charging and discharging are stopped when the temperature of electrochemical accumulation subsystems exceeds the temperature limit which is indicated by the manufacturer.
- In the case that a current limiting device is equipped outside the electrochemical accumulation subsystems, the function of the current limiting device shall be checked by system validation or by testing with suitable simulated signals of overcharging or temperature rise.

Upon installation, any functions of overheating detection systems, audible alerts and visual signals for reporting an incident of overheating shall be validated or tested in accordance with appropriate standards, manufacturer instructions and local regulations to confirm that their functions automatically operate when monitored temperature limits exceed those provided by the manufacturer. The type test for individual components of detection systems, audible alerts and visual signals shall be conducted.

For category "V-H" BESS, the SAT for the whole BESS installation with a combination of detection systems, audible alerts and visual signals shall be conducted.

All the functions above shall operate as designed.

Annex G provides further information regarding thermal control operation.

8.2.6.2 Abnormal operation of subsystems for ventilation

This test is conducted on BESS with ventilation systems or ventilation openings in the BESS enclosure. The ventilation system of the BESS is to be blocked or disconnected. The BESS is then to be subjected to any internal heat sources (i.e. discharge/charge cycle of electrochemical accumulation subsystems) to see if the controls detect the faulted ventilation system and if they end up charging and discharging before the BESS overheats. The test may be conducted with the ventilation system operating and any ventilation openings or ducts blocked.

The test is to be repeated with the ventilation system operating, but with any ventilation openings or ducts blocked.

Upon installation, the BESS shall be checked to ascertain if the detection of abnormal conditions of the ventilation subsystems is reported to operators.

Upon installation, the BESS shall be checked to ascertain if the function of report to the operator automatically operates when the temperature of electrochemical accumulation subsystems exceeds the temperature limit which is indicated by the manufacturer.

Any warning device functions shall be checked by system testing with suitable simulated signals.

All the functions above shall operate as designed.

8.2.6.3 Temperature under normal operation tests

When operated at maximum operating loads and parameters, temperatures on temperature sensitive components of the BESS shall be within their specified ratings. The operating parameters for electrochemical accumulation subsystems shall be within their specified operating parameters for voltage, current and temperatures.

The BESS shall be operated at maximum normal loading conditions for charging and discharging. During this operation, temperatures on temperature critical components including electrochemical accumulation subsystems and the voltage and current of the electrochemical accumulation subsystems shall be monitored to determine whether or not they are operating within their specified temperature, current and voltage range.

All the functions above shall operate as designed.

8.2.7 Chemical effects

8.2.7.1 Specification of hazardous fluids

The hazardous fluids which need to be detected shall be first identified and specified during the appropriate system design process.

NOTE The outcome of this requirement will depend on the chemistry of the electrochemical accumulation subsystem. See Annex B.

8.2.7.2 Fluids detection

Upon installation, any functions of the detection systems, audible alerts and visual signals for reporting an incident of hazardous fluids shall be tested in accordance with appropriate standards, manufacturer instructions and local regulations to confirm that their functions automatically operate when the concentration or leakage of hazardous fluids occurs. Their functions shall operate as designed. The SAT for individual components of detection systems, audible alerts and visual signals shall be conducted with suitable simulated signals for the events to be detected.

These tests can be conducted as a type test if hazardous chemical sensors and alarm systems are provided as part of the BESS rather than as a protection system installed as part of the installation site.

8.2.7.3 Protective measures against hazardous fluid

Any functions of protective measures against hazardous fluid required in 7.11.3.1 shall be validated or tested in accordance with appropriate standards, manufacturer instructions and local regulations. Their functions shall operate as designed.

8.2.8 Hazards arising from auxiliary, control and communication system malfunctions

The tests to determine if hazards result from an auxiliary system malfunction, control system malfunction, internal communication system malfunction and external communication system malfunction of the BESS are to be conducted in accordance with IEC TS 62933-5-1. Analysis of the system shall provide guidance on possible faults to these subsystems of the BESS.

The correct operation of safety interlocks shall be validated in accordance with the processes specified in 8.2.8.

The BESS parameters shall be available over a communication network even when the system is shut down correctly.

All the functions above shall operate as designed.

8.2.9 Hazards arising from environments

8.2.9.1 General

The tests noted below apply to those BESS that have environmental ratings or intend to be installed where environmental conditions can affect their safety.

8.2.9.2 Exposure to moisture ingress

The BESS shall be confirmed by a system design check in accordance with the result of the system level risk assessment (see Clause 6) or by a complete testing of its claimed ingress protection (IP) (environmental) rating in accordance with IEC 60529.

If the BESS are to be tested for the ingress of moisture, the BESS shall not exhibit signs of fire or explosion, and there shall be no damage to the enclosure that would result in access to hazardous parts in accordance with 8.2.10. The protective subsystems shall remain functional. The BESS shall not pose an electrical shock hazard as determined by compliance to the dielectric voltage withstand test of 8.2.1.4.

BESS that are intended to be installed in locations that can be subject to flooding shall be subject to a water immersion exposure test using salt water that has a weight of 5 % NaCl in H₂O. The BESS shall be completely immersed or portions of the BESS that would be impacted by water immersion are to be immersed for 2 h or until reactions appear to have stopped. As a result of the immersion, there shall be no fire or explosion.

In case of toxic gas or fluid release in the presence of water, gas or fluids shall be detected. They shall be identified (nature) and specified (released volume) during the appropriate system design process. Protection from chemical effects shall be provided as described in 7.11.3.6.

The process that is required to comply with the above is included in the testing example that is given in Annex D.

8.2.9.3 Exposure to marine environments (salt fog)

BESS intended for installation in or around a marine environment (e.g. near seashores, on docks, etc.) shall be confirmed by a system design check in accordance with the result of the system risk assessment (see Clause 6) or wholly subjected to the exposure test method 1 or 2 specified in IEC 60068-2-52.

NOTE IEC 60068-2-52 defines test method 1 or 2 for equipment which is continuously used in or around a marine environment

As a result of the salt fog exposure, the BESS shall not exhibit signs of fire or explosion. There shall be no damage of the enclosure that would result in access to hazardous parts. The BESS shall not pose an electric shock hazard as determined by compliance to the dielectric voltage withstand test of 8.2.1.4.

In case of toxic gas or fluid release in presence of salt water, gas or fluids shall be detected. They shall be identified (nature) and specified (released volume) during the appropriate system design process. Protection from chemical effects shall be provided as described in 7.11.3.6.

The possible process that is to be done for complying with the above is included in the testing example shown in Annex D.

8.2.10 IP rating of BESS enclosure and protective guards

The BESS enclosure and protective guards shall comply with their IP rating for access to hazardous parts (e.g. hazardous moving parts, uninsulated electrical parts at hazardous voltage) in accordance with IEC 60529.

9 Guidelines and manuals

In addition to the requirements in 7.12, and 7.13.1.1 to 7.13.1.4, the considerations in IEC TS 62933-5-1:2017, Clause 9, are applicable.

Annex A (informative)

Ownership models of BESS

This document deals with safety and does not decide the ownership of BESS, but the decision and clarification of ownership are important for BESS safety and responsibility for them, so the description of ownership models is also important because that is helpful for decision of ownership.

Ownership models are a critical consideration for BESS, particularly in smaller domestic and commercial installations. Where larger installations would generally form part of a larger utility system, having specific procedures and tasks assigned, smaller installations would likely be regarded in the same manner as household appliances such as a refrigerator. In this instance it should be assumed that the system user has neither technical expertise nor a satisfactory level of consciousness as to the safety aspects of BESS. Where this situation is likely to be prevalent in the future, the following should be considered:

- should the system be sold outright with no ongoing engagement between the system owner and/or supplier?
- would the safety and performance goals of the system be better achieved through a managed lease model?
- is the option of a managed lease or contracted service regime practical or cost effective?
- should this aspect be subject to regulation?
- does the ownership model necessarily restrict the type of chemistries that can be installed in these smaller installations?
- what are the impacts of transfer of ownership where an incoming owner may not even be aware the BESS exists?
- what level of engagement is required with the electrical supply utility where the BESS is on the consumer's side of the electrical meter; what are the rights of the utility in this circumstance?
- at what point does the system become a significant risk to require regulatory measures, when the most basic BESS could have the size and simplicity of a basic UPS system where the only difference is bi-directional flow?
- what end-of-life outcomes can be relied upon under different ownership models?

Annex B (informative)

BESS hazards and risks

B.1 General introduction

Battery energy storage systems (BESS) that are designed with sufficient safety protections and are installed, operated, and maintained in a manner that maintains the system safety can be operated without incident as evidenced by the systems currently operating safely in the field. The safety controls and hazard mitigation approach need to consider the inherent hazards associated with these systems, which can vary depending on the battery technology.

All electrochemical energy storage systems have several risks in common. These include:

- the inability to always be able to isolate the energy or reduce it to safe levels, giving rise to a potential risk of electrical shock or other electrical energy hazards,
- batteries can provide a large DC short-circuit current,
- chemical hazards due to electrolyte release,
- battery constituents can be flammable,
- batteries can generate gases as part of normal operation (hydrogen) or because of abnormal operation (e.g. chlorine, bromine, H₂S, SO₂),
- batteries modules can be heavy,
- failure of communication link (internal or external) affecting the system's ability to enter a safe state.

The main conditions leading to hazards commonly pertaining to all BESS listed in Table 1 include but are not limited to:

- error of earth fault detection of the "BESS" itself,
- loss of control of the electrochemical accumulation subsystem(s) while in a charged condition (especially malfunction caused by the other subsystems, e.g. oscillation and/or noise of power conversion subsystem),
- collapse, drop and physical oscillation (vibration) of the electrochemical accumulation subsystem and housing,
- malfunction of subsystems caused by electric noise and electromagnetic (or electrostatic) induced vibration,
- foreseeable misuse conditions of the batteries and final installed system, and
- compatibility of chosen batteries and the final system as designed.

The principal hazards of BESS in category "C-A: using non-aqueous electrolyte battery" include but are not limited to:

- thermal propagation originating from an uncontrolled failure in the electrochemical accumulation subsystem(s),
- combustible release of gas from the electrochemical accumulation subsystem(s),
- fire induced chemical/toxic threats originating from the electrochemical accumulation subsystem(s).

The principal hazards of BESS in category "C-B: using aqueous electrolyte battery" include but are not limited to:

- combustible chemical (e.g. hydrogen gas) propagation from the electrochemical accumulation subsystem(s),
- toxic chemical (e.g. electrolyte) propagation from the electrochemical accumulation subsystem(s).

The principal hazards of BESS in category "C-C: using high temperature battery" include but are not limited to:

- thermal propagation originating from uncontrolled failure in the electrochemical accumulation subsystem(s),
- abnormal heat from the electrochemical accumulation subsystem(s).

The principal hazards of BESS in category "C-D: using flow battery" include but are not limited to:

- combustible chemical (e.g. hydrogen gas) propagation from the electrochemical accumulation subsystem(s)
- toxic chemical (gas, liquid) propagation from the electrochemical accumulation subsystem(s)

Table B.1 to Table B.5 show the lists of hazards of BESS. These tables are just for clarification of the hazards to be considered for the risk assessment process of the BESS, and not those of the individual batteries themselves.

The performed risk analysis can consider the relevant categorizations within 4.2 and the overall risk of the BESS including but not limited to:

- risks associated with aggregation of multiple components and/or battery units,
- complexity of final system and failure modes,
- any considerations to take account of the safety across the life cycle usage of the BESS,
- inadequate earthing, insulation and connection among BESS subsystems,
- hazardous (restrictive, confined, limited) workspace,
- water and dust ingress (unsuitable IP grade),
- transient electrical input in the connected grid.

Table B.1 – Hazards of BESS in common

"System hazard" – combination with each subsystem			
Kind		Hazards as "subsystem incidents" (yes or no / details)	
Electrical		Y	Inadequate earthing essential for safety in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, and housing Error of earth fault detection in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, housing and connection terminal to grid Losing control of electrochemical accumulation subsystem with energy in combination with power conversion subsystem, management/communication subsystem, protection subsystem, housing, connection terminal to grid and interfaces Inadequate insulation essential for safety in combination with electrochemical accumulation subsystem, power conversion subsystem, housing, and connection terminal to grid Inadequate connection essential for safety in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem and protection subsystem
Mechanical		Y	Collapse, drop and physical oscillation of electrochemical accumulation subsystem and housing
Electric, magnetic, and electromagnetic fields		Y	Malfunction of subsystems caused by electric noise and physical oscillation of subsystems caused by magnetic noise in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, housing and connection terminal to grid
"Hazard concerning location, environment, and application"			
Location			
Category		Hazards (yes or no / details)	
Mechanical		Y	Vibration, impact
Dangerous working conditions		Y	Hazardous (restrictive, confined, limited) workspace
Environment			
Category		Hazards (yes or no / details)	
Waterfront		Y	Water ingress
Application			
Category		Hazards (yes or no / details)	
Any case		Y	High voltage, excess current

**Table B.2 – Hazards of BESS using non-aqueous electrolyte battery
(category "C-A")**

"System hazard" – combination with each subsystem		
Kind	Hazards as "subsystem incidents" (yes or no / details)	
Electrical	Y	In addition to Table B.1: Internal short-circuit of battery cell in combination with electrochemical accumulation subsystem, management/communication subsystem and housing Internal short-circuit of electrochemical accumulation subsystem in combination with electrochemical accumulation subsystem, management/communication subsystem and housing
Explosion	Y	Retention of combustible gas in combination with electrochemical accumulation subsystem and HVAC subsystem Sparking in combination with electrochemical accumulation subsystem, power conversion subsystem, protection subsystem, housing and connection terminal to grid Insulation breakdown in electrochemical accumulation subsystem in combination with management/communication subsystem and protection subsystem Fusing of conductor in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, housing and connection terminal to grid Increase of inner pressure in electrochemical accumulation subsystem in combination with management/communication subsystem and HVAC subsystem
Fire	Y	Fire from electrochemical accumulation subsystem in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, HVAC subsystem, housing and connection terminal to grid Propagation of thermal runaway from electrochemical accumulation subsystem in combination with electrochemical accumulation subsystem, management/communication subsystem, protection subsystem, housing and connection terminal to grid Fire from the other subsystem in combination with management/communication subsystem, protection subsystem, housing and interfaces
Temperature	Y	Exposure of heated surface in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, HVAC subsystem, housing and interface
Chemical	Y	Liquid spill, gas release, and solid emission from electrochemical accumulation subsystem (electrolytes, active materials, and reaction products) in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem and HVAC subsystem

**Table B.3 – Hazards of BESS using aqueous electrolyte battery
(category "C-B")**

"System hazard" – combination with each subsystem			
Kind	Hazards as "subsystem incidents" (yes or no / details)		
Electrical	Y	Same as Table B.1	
Explosion	Y	Retention of combustible gas in combination with electrochemical accumulation subsystem and HVAC subsystem Sparking in combination with electrochemical accumulation subsystem, power conversion subsystem, protection subsystem, housing and connection terminal to grid Fusing of conductor in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, housing and connection terminal to grid Increase of inner pressure in electrochemical accumulation subsystem in combination with management/communication subsystem and HVAC subsystem	
Fire	N	N/A	
Temperature	N	N/A	
Chemical	Y	Liquid spill and gas release from electrochemical accumulation subsystem (electrolytes, active materials, and reaction products) in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem and HVAC subsystem	

**Table B.4 – Hazards of BESS using high temperature battery
(category "C-C")**

"System hazard" – combination with each subsystem		
Kind	Hazards as "subsystem incidents" (yes or no / details)	
Electrical	Y	In addition to Table B.1: Internal short-circuit of electrochemical accumulation subsystem in combination with management/communication subsystem and housing Battery heating circuit failure in combination with electrochemical accumulation subsystem, management/communication subsystem and protection subsystem
Explosion	Y	Dissolution of battery and conductive parts by negative electrode material (sodium) in combination with electrochemical accumulation subsystem, management/communication subsystem, protection subsystem and battery heating circuit Sparking in combination with electrochemical accumulation subsystem, power conversion subsystem, protection subsystem, housing and connection terminal to grid Insulation breakdown in electrochemical accumulation subsystem in combination with management/communication subsystem and protection subsystem Fusing of conductor in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, housing and connection terminal to grid Increase of inner pressure in electrochemical accumulation subsystem in combination with management/communication subsystem and HVAC subsystem
Fire	Y	Fire from electrochemical accumulation subsystem in combination with management/communication subsystem, protection subsystem, HVAC subsystem, battery heating circuit, housing and connection terminal to grid
Temperature	Y	Exposure of heated surface in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, HVAC subsystem, battery heating circuit, housing and interface Battery heating circuit failure in combination with electrochemical accumulation subsystem, management/communication subsystem and protection subsystem
Chemical	Y	Liquid spill, gas release, and solid emission from electrochemical accumulation subsystem (electrolytes, active materials, and reaction products) in combination with management/communication subsystem, protection subsystem, HVAC subsystem and battery heating circuit Chemical reaction of sodium with water in combination with electrochemical accumulation subsystem, management/communication subsystem and protection subsystem

Table B.5 – Hazards of BESS using flow battery (category "C-D")

"System hazard" – combination with each subsystem			
Kind	Hazards as "subsystem incidents" (yes or no / details)		
Electrical	Y	Same as Table B.1	
Explosion	Y	Retention of combustible gas in combination with electrochemical accumulation subsystem and fluid system Sparking in combination with electrochemical accumulation subsystem, power conversion subsystem, protection subsystem, housing and connection terminal to grid Fusing of conductor in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, protection subsystem, housing and connection terminal to grid	
Fire	N	N/A	
Temperature	Y	Exposure of heated surface in combination with electrochemical accumulation subsystem, power conversion subsystem, management/communication subsystem, heat exchanger, fluid system, housing and interface Temperature control error in combination with management/communication subsystem and heat exchanger	
Chemical	Y	Liquid spill and gas release from electrochemical accumulation subsystem (electrolytes, active materials, and reaction products) in combination with electrochemical accumulation subsystem, heat exchanger and fluid system Gas generation by electrolysis of water in combination with electrochemical accumulation subsystem and management/communication subsystem	

B.2 Hazard concerns

B.2.1 General

The hazards that need to be addressed for BESS are fire and explosion hazards, chemical hazards, electrical hazards, stored energy hazards, and physical hazards. These hazards can vary by technology but can also vary under normal operating conditions compared with emergency and abnormal conditions.

B.2.2 Fire hazards

The potential for fire hazards can be evaluated through control of the elements of the fire triangle. These elements are the fuel for the fire, the oxidant, and the ignition source heat. There is no potential for fire unless there is an appropriate concentration of fuel, oxidant, and a heat source sufficient to ignite the concentration.

B.2.3 Chemical hazards

Chemical hazards are categorized in accordance with hazardous material limits for normal operation of the BESS.

B.2.4 Electrical hazards

Electrical hazards for persons working with BESS where they might come in contact with energized parts greater than 50 V and exposed to arcing of electric energy with an incident energy level of 1,2 cal/cm² (5 J/cm²) (potential to cause second-degree burns on skin), are electrical shock and arc flash. Electrical hazards to emergency responders from BESS that have been exposed to fire or other emergency incidents need to be addressed, including the potential for electrical shock and arc flash hazards due to shorting from damaged parts of BESS and water around them. Since first responders are not trained electrical workers and might not have appropriate PPE for direct contact with live parts or arc flash incidents, acceptable levels of voltage and incident energy need to be reduced from that allowed for trained workers with suitable PPE.

B.2.5 Energy hazards

The term stored energy refers to unknown hazardous levels of electrical energy that can be contained in all or parts of BESS, including one that has been damaged and/or thought to be discharged and represents a hazard to persons in contact with the system, who are unaware of the hazardous energy. Since this hazard represents a potential unknown electrical hazard, the allowed levels will be different depending on whether they pertain to normal conditions for repair and replacement by trained workers or to emergency responders dealing with damaged BESS that can still contain hazardous energy.

B.2.6 Physical hazards

Physical hazards are hazards to persons that can occur from contact with parts having sufficient kinetic energy, parts that have hazardous thermal characteristics that can cause burns, or parts that contain fluids at hazardous pressure levels with either insufficient structural integrity to safely contain the fluids or the ability to safely relieve the pressure. For electrochemical BESS, the potential exists for burn hazards to workers in contact with some technologies during normal operation and repair, if not properly thermally insulated.

B.2.7 High-pressure hazards

There are no known high-pressure hazards with these systems under normal operations, but under abnormal conditions, there can be over-pressurization due to overheating of contents, which can result in a physical hazard. This could present a hazard to first responders dealing with damaged BESS. There is typically no kinetic energy hazard associated with commercially available BESS, except for moving parts in the balance of plant components of the system that might not be properly guarded, such as cooling or ventilation fan blades.

B.3 Hazard considerations under normal operating conditions

B.3.1 Fire and explosive hazards

Fire and explosive hazards under normal operating conditions can be due to heat sources such as live parts, and so forth, that can be in contact with combustible materials during service or maintenance or to ignition of combustible concentrations of flammable fluids and solids that can occur as part of the normal operation of BESS, such as hydrogen release from batteries with aqueous electrolytes.

B.3.2 Chemical hazards

Under normal operating conditions, the potential exists for exposure to hazardous materials by workers in contact with the system for maintenance, repair, and replacement of systems.

Examples of chemical hazards are as follows:

1) Examples of liquid hazards:

- a) Corrosive electrolytes: Batteries with electrolytes in the range of $\text{pH} \leq 2$ or $\geq 11,5$ are considered corrosive (acid or caustic). This is an issue with systems with these electrolytes, where there is a risk of leaks or spills during maintenance or normal operation. There should be measures for spill containment, and workers should have appropriate safe work procedures and protective clothing to work around systems with these corrosive liquids. This does not apply to lead acid batteries of the VRLA type.
- b) Toxic liquids: The potential exists for exposure to toxic liquids during normal operating, servicing, and maintenance of some systems. Guidance for worker exposure to toxic liquids can be found in GHSs (globally harmonized systems). Workers in contact with these systems need to be aware of potential hazards and have appropriate procedures and equipment/PPE to avoid these hazards.

- 2) Oxidizers: The potential exists for oxidizers to be present within the BESS. An oxidizer will increase the flammability potential of other materials.

- 3) Toxic gases: The potential exists for exposure to toxic gases under normal conditions of maintenance and service of some BESS systems.

NOTE 1 The concentrations of these gases would be limited in accordance with applicable code and local regulations.

NOTE 2 For example, OSHA and NIOSH provide guidance for exposures, including permissible exposure limits (PEL), recommended exposure limits (REL) for exposure during an 8 h or 10 h workday, ceiling limits, which are the upper limit of a safe exposure, and IDLH, which represents concentrations that are immediately dangerous to life and health.

- 4) Solids: Water-reactive and toxic metals that might be contained in some battery technologies typically are not exposed during routine maintenance and servicing of these systems but can present issues under abnormal conditions. Batteries containing these hazardous materials should be marked with suitable symbols conforming to the results of risk analysis and local regulations.

B.3.3 Electrical hazards

Under normal operating conditions some battery systems might have electrical hazards that need to be addressed as part of operation and maintenance. Electrical hazards that can occur during normal operating conditions include:

- 1) Electrical shock: BESS with voltages above 50 V can pose hazards to trained workers who might come in contact with live parts during operation and servicing of the systems. It is necessary that appropriate labeling and procedures and protective equipment are utilized by workers when servicing these systems.
- 2) Arc flash: BESS that have an incident energy level greater than 5 J/cm² (23,8 ft·lb/in²) should have the arc flash boundaries calculated, identified through markings, and proper procedures and equipment in place to prevent worker injury from arc flash during normal operation and servicing.
- 3) Stored energy hazards: Energy that can be accumulated and reserved for future use, generally in the form of electricity, is stored energy. An example of a stored energy hazard is worker exposure to BESS that are not discharged sufficiently or BESS that are damaged and where the potential exists for electric shock and arc flash. For normal operating conditions, locations housing commercial and industrial BESS should maintain onsite instructions for isolation of hazardous voltage and energy for maintenance, and for discharging batteries for safe replacement and disposal. Residential and smaller commercial systems should have information provided and access to trained technicians to perform these duties to ensure that stranded and stored energy does not represent a hazard under normal operating conditions.

B.3.4 Physical hazards

Physical hazards can include the following:

- 1) Burn hazards: Potential contact with hot surfaces during maintenance that could result in burns if PPE is not worn.
- 2) Parts containing pressurized fluids, including compressed gases.
- 3) Parts with kinetic energy: Parts of the BESS balance of plant components that might contain moving parts that could cause injury if not guarded properly. This might also be an issue for a hybrid system of batteries and flywheels.

B.4 Hazard considerations under emergency/abnormal conditions

B.4.1 Fire hazards

Fire hazards can include the following:

- 1) Combustible/flammable concentrations due to overheating and venting of flammable gases near sources of ignition can occur during emergency/abnormal conditions. If concentrations of vented gases such as hydrogen are sufficient to create combustible/flammable concentrations in the presence of hot parts, there will be ignition resulting in either a fire or an explosion. All batteries, with the exception of hermetically sealed types such as NaNiCl and NaS, have means to relieve internal pressure when overheated to prevent explosions of the battery cell from over-pressurization.
- 2) There can be fires due to overheating of electrical parts under abnormal conditions such as short-circuits.
- 3) Some BESS use inert gases for fire suppression. These gases are not toxic but can cause suffocation. Inadvertent leakage of the gases should be prevented.

B.4.2 Chemical hazards

Examples of chemical hazards are as follows:

- 1) Examples of liquid hazards:
 - a) Corrosive spills: A liquid with a pH ≤ 2 or $\geq 11,5$ is considered corrosive and hazard level 3 and can cause serious or permanent eye injury for someone who comes in direct contact with it according to NFPA 704:2017, Table B.1. With some systems that contain corrosive liquids, there can be the possibility of leaks or spills from the system under emergency/abnormal conditions. Batteries containing corrosive liquids are to be marked health hazard level 3 in the NFPA 704 hazard diamond.
 - b) Toxic liquid vapor exposure: There are different levels of toxicity from liquid vapors that can occur under emergency conditions such as fires and hazardous leaks and spills. There is a range of hazard levels outlined in NFPA 704 as follows:
 - i) Level 4: Is lethal under emergency conditions. Any liquid whose saturated vapor concentration at 68°F (20 °C) is equal to or greater than 10 times its LC50 for acute inhalation toxicity, if its LC50 is less than or equal to 1 000 parts per million (ppm).
 - ii) Level 3: Can cause serious or permanent injury. Any liquid whose saturated vapor concentration at 68 °F (20 °C) is equal to or greater than its LC50 for acute inhalation toxicity, if its LC50 is less than or equal to 3 000 ppm, and that does not meet the criteria for degree of hazard 4.
 - iii) Level 2: Can cause temporary incapacitation or residual injury under emergency conditions. Any liquid whose saturated vapor concentration at 68 °F (20 °C) is equal to or greater than one-fifth its LC50 for acute inhalation toxicity, if its LC50 is less than or equal to 5 000 ppm, and that does not meet the criteria for either degree of hazard 3 or degree of hazard 4.
 - iv) Level 1: Can cause significant irritation under emergency conditions. Mists whose LC50 for acute inhalation toxicity is greater than 10 mg/L but less than or equal to 200 mg/L.
- 2) Oxidizers: The potential exists for oxidizers to be present within the BESS. An oxidizer will increase the intensity of a fire of other materials. NFPA 400:2019, Annex G, provides information on tests to classify an oxidizer material and identifies known oxidizing materials under their classifications. NFPA 400:2019, Annex G, also provides guidance on safety measures to use when there are significant exposed quantities of known oxidizers, which can occur during abnormal conditions of certain BESS technologies that contain them. Batteries containing oxidizers are to be marked in the special hazard section of the NFPA 704 hazard diamond.

- 3) Solids: Some battery technologies contain water-reactive materials that can react violently when in contact with moisture, including moisture in the air. Although not exposed under normal operating conditions, these materials could be exposed under abnormal conditions. Batteries containing water-reactive substances should be marked as such in the NFPA 704 hazard diamond.
- 4) Gases — toxic gases: Similar to toxic vapors emanating from liquids, there are different levels of hazards associated with toxic gases from level 4 to level 1:
 - a) Level 4: Gases that can be lethal under emergency conditions; gases whose LC50 for acute inhalation toxicity is less than or equal to 1 000 ppm.
 - b) Level 3: Gases that can cause serious or permanent injury under emergency conditions; gases whose LC50 for acute inhalation toxicity is greater than 1000 ppm but less than or equal to 3 000 ppm.
 - c) Level 2: Gases that can cause temporary incapacitation or residual injury under emergency conditions; gases whose LC50 for acute inhalation toxicity is greater than 3 000 ppm but less than or equal to 5 000 ppm.
 - d) Level 1: Gases that can cause significant irritation under emergency conditions; gases and vapors whose LC50 for acute inhalation toxicity is greater than 5 000 ppm but less than or equal to 10 000 ppm.

NOTE As outlined in NFPA 704, LC50 for acute toxicity on inhalation is that concentration of vapor, mist, or dust, which, when administered by continuous inhalation to both male and female young adult albino rats for 1 h, is most likely to cause death within 14 days in one half of the animals tested. The criteria for inhalation toxicity of vapors are based on LC50 data relating to 1 h exposures.

B.4.3 Electrical hazards

Examples of electrical hazards are as follows:

- 1) Electrical shock: Circuits with voltages above 50 V have the potential for electrical shock hazards, because first responders under emergency conditions would not have the training and protective equipment that trained electrical workers would have under normal servicing and maintenance conditions. Information needs to be available for maintenance staff and first responders on how to address electrical hazards.

In addition, under emergency conditions the potential exists for emergency responder exposure to live parts in contact with conductive fluids such as water and live parts exposed as a result of abnormal conditions. Manufacturers/installers of BESS should define standoff distance and type and angle of water spray for first responders. Emergency response guidelines should address the issue of isolation of hazardous voltages.

NOTE UL research into the issue of potential shock to fire fighters from water spray on PV fires indicated that the electric shock hazard due to application of water is dependent on voltage, water conductivity, distance, and spray pattern. For example: (1) A slight adjustment from a solid stream toward a fog pattern (a 10° cone angle) reduced measured current below perception level. (2) Salt water should not be used on live electrical equipment. (3) A distance of 6,1 m (20 ft) had been determined to reduce potential shock hazard from a 1 000 V DC source to a level below 2 mA considered as safe.

- 2) Shock, arc flash, and arc blast hazards: First responders are generally not provided with training and proper protection from arc flash, arc blast, and shock hazards, including clothing, gloves, and so forth, so the potential for sufficient energy that will result in a hazardous electrical event occurring during an emergency response exists. Manufacturers should provide emergency response guidance on how to reduce arc flash and blast hazards.
- 3) Stored energy hazards: BESS damaged during an emergency incident can present potential shock, arc flash, arc blast, and re-ignition hazards. Sites should have access to on-call trained staff to assist in emergency situations to isolate potential hazard energy and, if necessary, to drain energy to prevent potential re-ignition of some technologies. For commercial and industrial installations, there needs to be trained personnel available for emergency response on site. For residential and smaller scale commercial systems, on-call trained personnel need to be made available to assist first responders and address discharging of stored energy in batteries for disposal.

B.4.4 Physical hazards

Examples of physical hazards are as follows:

- 1) Hazardous pressures can develop due to overheating of equipment and devices that do not have pressure relief means (e.g. some chemistries such as flow batteries, etc.).
- 2) Potential hot parts.
- 3) Exposed parts with hazardous kinetic energy sufficient to cause bodily harm for persons coming in contact with them, such as exposed fan blades, and so forth, under abnormal conditions.

B.5 Commercially available battery technologies

B.5.1 Lithium ion (Li-ion) batteries (C-A)

The term lithium-ion battery refers to a battery where the negative electrode (anode) and positive electrode (cathode) materials serve as a host for the lithium ion (Li^+). Lithium ions move from the anode to the cathode during discharge and are intercalated into (inserted into voids in the crystallographic structure of) the cathode. The ions reverse direction during charging. Since lithium ions are intercalated into host materials during charge or discharge, there is no free lithium metal within a lithium-ion cell and thus, even if a cell does ignite due to external flame impingement or an internal fault, metal fire suppression techniques are not appropriate for controlling the lithium-ion fire.

Hazard considerations for Li-ion batteries under normal operating conditions are as follows:

- 1) Fire hazards: There can be the potential for fire hazards if there are latent defects within the cells or design issues with the controls that prevent thermal runaway of the cells. Systems need to be evaluated for their ability to prevent propagation due to these defects.
- 2) Chemical hazards: Not applicable.
- 3) Electrical hazards: There are electrical hazards associated with routine maintenance of these batteries if they are at hazardous voltage and energy levels.
- 4) Stored energy hazards: There can be the potential for stored energy hazards during maintenance if the batteries cannot be isolated for maintenance or replacement.
- 5) Physical hazards: Not applicable.

Hazard considerations for Li-ion batteries under emergency/abnormal conditions are as follows:

- a) Fire hazards: There can be the potential for thermal runaway if the batteries are not maintained at appropriate operating parameters as a result of abnormal conditions. Also, there might be fire hazards due to short-circuiting abnormal conditions.
- b) Chemical hazards: There can be the potential for off-gassing of hazardous vapors under abnormal conditions depending on the size of the cells and the level of failure.
- c) Electrical hazards: Electrical hazards might be present under abnormal conditions if the system is at hazardous voltage and energy levels.
- d) Stored energy hazards: There can be the potential for stranded energy hazards if the batteries are exposed to abnormal conditions. Damaged batteries might contain stored energy that can be a hazard during disposal if care is not taken.
- e) Physical hazards: Depending on the design of the system, the potential exists for physical hazards under abnormal conditions if accessible parts are overheating or if there is exposure to moving hazardous parts such as fans where guards might be missing.

B.5.2 Lead-acid batteries (C-B)

B.5.2.1 General description

Lead-acid batteries have lead dioxide as the active material of their positive electrode and metallic lead as the negative electrode with a 1,28 specific gravity (at 28 °C) sulfuric acid solution electrolyte. During discharge, both positive and negative electrodes are converted to lead sulfate. There are two basic categories of lead-acid batteries:

- 1) Vented lead-acid batteries, also called wet cell or flooded lead-acid batteries.
- 2) Valve-regulated lead-acid (VRLA) batteries, sometimes referred to as starved electrolyte or maintenance-free batteries.

Vented lead-acid batteries require ongoing maintenance of the electrolyte, and the contents of the battery are open to the atmosphere through a vent/flame arrester assembly. VRLA batteries are generally sealed to the atmosphere and contain a valve that can open when pressure builds up in the battery and then close again. The electrolyte in VRLA batteries is immobilized either through use of a gel electrolyte or through absorption of the electrolyte in a porous absorptive glass matseparator.

B.5.2.2 Vented lead-acid batteries

Hazard considerations for vented lead-acid batteries under normal operating conditions are as follows:

- 1) Fire hazards: The generation of hydrogen is related to the flow of the charging current once the battery is fully charged. This current increases with increasing battery temperature and is potentiated by excessive charge voltages ($V > 2,45 V_{pc}$). IEC 62485-2 gives appropriate guidance in this matter. Upon discharge no hydrogen is produced but a small temporary release from the cell can occur nevertheless in the form of hydrogen trapped in the negative active mass and now liberated during the discharge.
- 2) Chemical hazards: There is the potential for contact with the sulfuric acid electrolyte because these batteries require maintenance and are open to the atmosphere. Workers near these batteries need to use suitable PPE and take care to prevent exposure to acid when working around the batteries. These systems should be provided with spill control and neutralization according to codes.
- 3) Electrical hazards: There are electrical hazards associated with routine maintenance of these batteries if they have been at hazardous voltage and energy levels.
- 4) Stored energy hazards: There can be the potential for stored or stored energy hazards during maintenance if the batteries cannot be isolated for maintenance or replacement of batteries.

Hazard considerations for vented lead-acid batteries under emergency/abnormal conditions are as follows:

- a) Fire hazards: There is the potential for concentrations of hydrogen from vented lead-acid batteries due to overheating from abnormal conditions if the area where the batteries are located is not properly ventilated. Another area that can create problems during abnormal conditions is the potential for the shorting of high current circuits.
- b) Chemical hazards: There is the potential for contact with the corrosive sulfuric acid electrolyte during abnormal conditions, should acids leak or bubble out through openings that might be created if spill containment is not present or large enough to contain large quantities of leaked electrolyte. First responders, in emergency situations, need to be aware of potential acid spills that can occur and take appropriate caution around these batteries.
- c) Electrical hazards: Electrical hazards might be present under abnormal conditions if the system is at hazardous voltage and energy levels.
- d) Stored energy hazards: There can be the potential for stored or stranded energy hazards if batteries are subject to abnormal conditions.

B.5.2.3 Valve-regulated lead-acid batteries (VRLA)

Hazard considerations for VRLA batteries under normal operating conditions are as follows:

- 1) Fire hazards: VRLA cells and mono-blocks emit hydrogen under all operating conditions. The ventilation requirements are specified in IEC 62485-2 for normal and boost charge conditions together with the appropriate safety distances to be implemented between the vent opening and a nearby spark or heat source. Under abnormal operating, i.e. overcharge, conditions the amount of hydrogen emitted can increase by a factor of 50.
- 2) Chemical hazards: These batteries are starved electrolyte types, so there should be no issue with exposure to corrosive electrolytes under normal operating conditions.
- 3) Electrical hazards: There are electrical hazards associated with routine maintenance of these batteries if they have been at hazardous voltage and energy levels.
- 4) Stored energy hazards: There can be the potential for stored energy hazards during maintenance if the batteries cannot be isolated for maintenance or replacement of batteries.

Hazard considerations for VRLA batteries under emergency/abnormal conditions are as follows:

- a) Fire hazards: There is the potential for off-gassing of hydrogen under abnormal conditions when batteries overheat. This can present a potential fire hazard due to combustible concentrations. There can be the potential for thermal runaway if the batteries are not maintained at appropriate operating parameters. Also, there can be fire hazards due to short-circuiting abnormal conditions.
- b) Chemical hazards: Although these batteries contain a corrosive electrolyte, they do not have as much free electrolyte that could result in spill hazards similar to vented types. There might be some minor release of electrolyte traces or potential for some leakage under abnormal conditions, if battery cases crack or leak.
- c) Electrical hazards: Electrical hazards might be present under abnormal conditions if the system is at hazardous voltage and energy levels.
- d) Stored energy hazards: There can be the potential for stored energy hazards if the batteries are exposed to abnormal conditions. Damaged batteries might contain stored energy that can be a hazard during dismantling or disposal if care is not taken.

B.5.3 Nickel batteries (C-B)

B.5.3.1 General description

Nickel batteries for stationary applications are divided into two main technologies: nickel-cadmium (Ni-Cd) and nickel-metal hydride (NiMH). Nickel-cadmium batteries have nickel hydroxide active material for the positive electrode and cadmium for the negative electrode with potassium hydroxide solution for the electrolyte. The nickel-cadmium batteries for stationary applications can be vented pocket-plate or vented sintered-plate batteries that are designed of multiple cells in a mono-block battery similar to a vented lead-acid battery. They also have vents for maintenance of the electrolyte. Nickel-cadmium batteries can also be sealed types, such as a fiber nickel-cadmium battery that is sealed and provided with a pressure relief valve similar to a VRLA battery. Nickel-metal hydride batteries have nickel hydroxide active material for the positive electrode, a metal hydride alloy for the negative electrode, and a solution of potassium hydroxide as the electrolyte. Nickel-metal hydride batteries are sealed in either a single cell design or a mono-block design with multiple internal cells and are provided with an enclosable valve for relieving pressure similar to a VRLA battery.

B.5.3.2 Nickel-cadmium (Ni-Cd) batteries

Hazard considerations for Ni-Cd batteries under normal operating conditions are as follows:

- 1) Fire hazards: There is the potential for concentrations of hydrogen from vented Ni-Cd batteries if the area where the batteries are located is not properly ventilated. However, this should be taken care of if the installation complies with the codes.