LOLABAT

“LOng LAsting BATtery”

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Abstract

Context and Objectives

This document represents the second deliverable of WP2 “Specification of requirements, norms and standards for the next generation of stationary batteries” and is part of the Task 2.2. “Assessment of norms and standards for RNZB”. The aim of this deliverable is to carry out a standardisation assessment and develop a standardisation roadmap for the rechargeable nickel-zinc battery (RNZB) technology. This will include a review of existing battery standards, on-going standardisation activities, and the future standardisation needs of the RNZB technology. This deliverable, together with D2.3. “Guidelines on regulatory aspects for RNZB batteries”, defines the regulatory and standardisation framework that will apply to RNZB batteries as well as the identification of regulatory gaps or areas of improvement.

Content

This deliverable contains a literature review of existing energy storage standards. This literature review is divided into two distinct sections. Section 3 provides a review of technology-agnostic standards, which apply to a variety of energy storage technologies (and different types of electrochemical energy storage systems). Section 4 provides a review of existing standards which are specific to a particular battery type or chemistry but are still relevant to the standardisation of RNZB batteries for use in energy storage applications.

Section 5 of this document highlights the main standards that the RNZB technology must comply with in order to access a range of markets and uses. Furthermore, this section also contains recommendations for future standardisation topics relevant to the RNZB technology. These future standardisation topics have been informed by existing standards related to other electrochemical battery technologies and the specific standardisation topics that fall outside of the more general, technology-agnostic standards documents.

Finally, the main conclusions of this report are outlined in section 6.

Attainment of the objectives and if applicable, explanation of deviations

The objectives of the deliverable and of the related task within LOLABAT project (T2.2.) have been achieved as planned. However, some technical information and specifications have been omitted from the summaries of existing standards documents due to copyright limitations imposed on the source documents.

Glossary

Abbreviation	Description
ANSI	American National Standards Institute
BESS	Battery Energy Storage System
BSI	The British Standards Institution
CAN	Canadian Standards Association
DC	Direct Current
DUT	Device Under Test
EES	Electrical Energy Storage
FELV	Functional Extra-Low Voltage
IEC	International Electrotechnical Commission
ISO	International Organisation for Standardization
LER	Light Electric Rail
NFPA	National Fire Protection Association
RNZB	Rechargeable Nickel-Zinc Battery
O&M	Operation and Maintenance
PELV	Protective Extra-Low Voltage
SELV	Safety Extra-Low Voltage
SoC	State of Charge
UL	Underwriter Laboratories
UPS	Uninterruptable Power Supply

Deliverable content

1. Introduction

Standards are important to ensure the consistent compliance to product safety and testing, quality, reliability, and environmental requirements. Furthermore, standards facilitate the interoperability of components made by different manufacturers, provide a common language to measure and evaluate component performance, and allow the required technology integration for markets to operate smoothly.

Battery standards cover a wide range of topics, from safety and performance requirements to standard testing procedures. These standards may apply to all energy storage systems, or to specific battery applications, such as portable or stationary uses. As well as this, several technology-specific standards exist, which provide specific details relevant to a particular type of battery cell or system.

With the LOLABAT project focussing on the development of the new rechargeable nickel-zinc battery, this document explores the existing standardisation topics that this technology will need to adhere to in order to gain access to the main stationary battery markets. This analysis of existing standards has been divided into two sections, standards that are technology-agnostic and apply to all (or a range of) energy storage technologies, and standards which are relevant to specific battery technologies, cell types or use cases. As well as the review of existing standards, the potential future nickel-zinc technology-specific standardisation activities are also explored. This includes an analysis of existing technology-specific standards to assess and inform the topics that will need to be covered in future RNZB battery specific standards.

The main standards bodies that have been assessed include the American National Standards Institute (ANSI), the British Standards Institution (BSI), the Canadian Standards Association (CAN), the International Electrotechnical Commission (IEC), the International Organisation for Standardization (ISO), the National Fire Protection Association (NFPA) and the Underwriter Laboratories (UL).

2 Objectives

The aims of this document include:

- To provide a literature review of the main existing standards that are related to battery energy storage systems used in stationary applications.
- To provide a literature review of existing standards that are specific to certain battery technologies and specific battery applications. This aims to inform the potential future standardisation activities related to the RNZB technology.
- To provide a review of the main standards that the RNZB technology will need to adhere to in order to gain access to a number of main markets.
- To provide an assessment of the likely future standardisation activities that will be required for the RNZB technology.

3 Literature review of existing standards – technology agnostic

3.1.1 General

3.1.1.1 IEC 62933-1 – Electrical Energy Storage (EES) systems Part 1: Vocabulary

This section of the IEC 62933 standard defines the relevant terms that are applicable to electrical energy storage systems. The terms included are necessary for the definition of unit parameters, test methods, planning, installation, safety, and environmental issues. The terms contained within this section include the following main classifications:

- Terms and definitions for ESS systems classification
- Terms and definitions for ESS systems specification
- Terms and definitions for ESS systems planning and installation
- Terms and definitions for ESS systems operation
- Terms and definitions for ESS systems safety and environmental issues

3.1.1.2 IEC TS 62933-4 - Electrical energy storage (EES) systems - Part 4-1: Guidance on environmental issues - General specification

This section of the IEC 62933 standard is a technical specification which outlines the environmental issues that are related to electrical energy storage systems. Guidelines are presented to address the environmental impacts of these systems, as well as the impact of the environment of the systems themselves. The impact on humans exposed to the environmental impacts of electrical energy storage systems are also covered. This document is applicable to all types of electrical energy storage systems, regardless of the specific energy storage technology that is employed.

The main content of this standard is divided into two sections. The first section focusses on the identification of environmental uses within ESS systems, with the distinction made between system to environment impacts and the environment to system impacts. The second main section details guidelines to be followed, which are separated into three groups:

- Guidelines for issues from the ESS system to the environment
- Guidelines for issues from the environment to the ESS system
- Guidelines for issues from the ESS system to humans with a chronic impact

3.1.1.3 IEEE 2030.2.1 - IEEE Guide for Design, Operation, and Maintenance of Battery Energy Storage Systems, both Stationary and Mobile, and Applications Integrated with Electric Power Systems

This standard introduces the main engineering requirements of BESS, with engineering approaches, key technical parameters, BESS application practises, and BESS operation and maintenance (O&M). IEEE 2030.2.1 is designed for use by BESS designers, integrators, and manufacturers. The standardization of BESS applications is assisted by the implementation of this guide document.

The content of this standard document is divided into the following main sections:

- BESS overview – This section contains the general considerations for battery energy storage systems. Furthermore, details are included regarding the configuration and connection of BESS, as well as the main functions of such systems.
- BESS design – The basic BESS design principles are outlined in this section, with system configuration and evaluation also outlined. The different types of installation are provided, and the design of energy

storage sub-systems is included. This section also covers the testing and commissioning processes associated with BESS design.

- BESS operation – Due to the number of potential different BESS functions, this section provides details regarding the operation characteristics of such functions. The battery management is also covered alongside the ability of the BESS to handle abnormal operation conditions.
- BESS maintenance – A general review of BESS maintenance is included in this section, as well as the maintenance of relevant power conversion systems. Specific details are provided for the maintenance of the following types of battery energy storage systems:
    - Lead-acid battery systems
    - Lithium-ion battery systems
    - Flow battery systems
    - Sodium-sulphur battery systems

It should be noted that this standard does not cover personal safety or network security aspects, or contract or supervision considerations.

3.1.2 Safety requirements

3.1.2.1 IEC 62485-1 - Safety requirements for secondary batteries and battery installations - Part 1: General safety information

The IEC 62485-1 standard details a number of basic requirements for secondary batteries and battery installations. The requirements of this standard are mainly specified for lead-acid and nickel-cadmium batteries but are also relevant to other battery systems with aqueous electrolyte, with the requirements being applied accordingly. This standard assists with the selection of the battery design and technology of secondary batteries. This is done by considering multiple requirements, including safety, reliability, life expectancy, mechanical strength, cycle stability, internal resistance, and battery temperature.

The safety aspects considered in this standard are associated with the following items:

- Electricity – installation, charging, discharging, etc.
- Electrolyte
- Inflammable gas mixtures
- Storage and transportation

The General information section in this standard includes information regarding the charging and discharging of batteries. This section provides basic information regarding battery charging techniques and procedures, as well as typical charger characteristics and multiple modes of operation. Basic discharge details are also included.

This standard contains specific topics which are covered in dedicated sections, with references to relevant specific standards and more detailed requirements provided in some cases. These dedicated topics are outlined in Table 1, below:

Table 1: IEC 62485-1 topics and content summary

Topic	Sub-topic	IEC 62485-1 content and standards references
Protection against electric shock	NA	• The required measures for protection against electric shock are based on the requirements detailed in IEC 60364-4-41 (Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock)
Disconnection and separation	NA	• Devices shall be included that can separate the battery from any incoming and outgoing current circuits and from protective earth.
Commissioning and putting batteries into operation	Delivery conditions of batteries	• Details the initial conditions of supplied batteries and the required procedures to put them into operation.
	Electrolyte and topping up water (vented & flooded cells)	• Properties of electrolyte and water for topping-up shall be compliant with the IEX 60993 standard for Nickel-cadmium. • Other battery chemistries shall be compliant with the manufacturer's specifications.
	Commissioning	• The following characteristics shall be compared to manufacturer's limits: voltages, currents, rest and charging periods and temperature.

Limit values and correction factors	NA	• The following values are specified and detailed to outline the safe operating conditions of the battery.
		  ○ Rated capacity and depth of discharge
		  ○ Charge current & charge voltage
		  ○ External short circuit parameters
		  ○ Battery temperature

Provisions against explosion hazards	NA	• This section outlines the need to consider the generation and build-up of flammable gasses and the resultant explosion risk if ignited at sufficient concentrations. • This risk is to be minimised via adjusted charging procedures, design, ventilation, and prevention of ignition.
Provisions against electrolyte hazards	NA	• The hazards of battery electrolyte exposure are outlined. • Battery manufacturers should provide safety instructions regarding this hazard.
Marking, labelling and instructions	NA	• The requirement for cells, batteries, and battery packs to be equipped with markings, labels or prints is outlined here.
Transport and storage	NA	• The relevant transportation regulations for different transportation methods are provided in this section.
Disposal and environmental aspects.	NA	• The relevant markings for electro-chemically active substances are provided in this section. • Reference is made to the appropriate standard: IEC 61429:1995

3.1.2.2 IEC 62485-2 - Safety requirements for secondary batteries and battery installations. Stationary batteries

This section of the IEC 62485 standard directly applies to stationary secondary batteries and battery installations with a maximum nominal voltage of direct current (DC) 1500V. It describes the main safety measures to provide protection against electricity, gas emission, and electrolyte hazards. It currently covers lead-acid, nickel-cadmium and nickel metal-hydride batteries, as well as aspects which are relevant to all stationary secondary battery systems.

Protection against electric shock – This section outlines measures to provide protection against either direct contact, indirect contact, or both. The measures in this section are detailed further in IEC 60364-4-41 and IEC 61140.

- Protection against direct contact – in battery installations, protection against direct contact with live parts must be ensured in line with the requirements in IEC 60364-4-41.
    - Protective measures include:
        - Protection by insulation of live parts
        - Protection by barriers or enclosures
        - Protection by obstacles
        - Protection by placing out of reach
- Protection against indirect contact – shall be aligned with IEC 60364-4-41 requirements.
    - Protective measures include:
        - Protection by automatic disconnection of supply – Various automatic disconnections of supply systems are provided in this section, including TN-systems, TT-systems, and IT-systems.
        - Protection by use of class II equipment or by equivalent insulation
        - Protection by non-conducting locations
        - Protection by earth-free local equipotential bonding
        - Protection by electrical separation
    - This section also outlines the protective devices that shall be used with direct current systems.
- Protection by automatic disconnection of supply

Disconnection and separation – In order to disconnect the battery installation from incoming and outgoing circuit lines (and from earth potential), one of several devices can be used:

- Circuit breakers, switches
- Plug and socket outlets
- Removable fuses
- Connecting links
- Specially designed clamps

These devices shall be applicable to direct current and the necessary separation distances in accordance with relevant standards shall be considered in their use.

Prevention of short circuits and protection from other effects of electric current – Electric shock hazards are not the only hazards considered in battery systems. The current flow in battery systems can cause other hazards as high currents may flow under fault conditions. The following hazard sub-topics are included within this section:

- Short-circuits – Short circuit of the battery terminals can result in considerable heat generation due to the high currents involved, with molten metal, sparks, explosion and vaporisation of electrolyte being included in the potential resultant hazards.

- Design requirements are outlined to provide adequate protection in the event of a short-circuit occurrence.
- A number of specific standards are referenced, including:
  - The type of conductor arrangement:
    - IEC 60364-4-42
    - IEC 60364-5-53
  - Calculation of the battery short circuit current:
    - IEC 61660-1
    - IEC 61660-2
    - IEC 60896-21.6.3
  - Procedures for working on live equipment:
    - IEC 60900

- Protective measures during maintenance – This section details the requirements to minimise the risk of injury to personnel working close to a battery system. Included in these requirements are a number of battery system design requirements and operating procedures to be followed.
- Leakage currents – Valve regulated batteries installed in orientations that put the sealing areas under stress shall meet the requirements in IEC 60896-22.6.5. Additional minimum requirements for insulation resistance, hazardous voltage verification and battery isolation determination prior to testing are included.

Provisions against explosive hazards – This section covers a range of requirements to ensure sufficient provisions are made to avoid potential explosive hazards within the battery system. The following topics, their aims, and content review are summarised in Table 2 below:

Table 2: IEC 62485-2 provision against explosive hazards content summary

Topic	Aim and content review
Gas generation	• The mechanisms behind gas emissions from secondary cells (excluding gastight sealed cells) are outlined in this section. The gasses produced are typically hydrogen and oxygen. • An explosive mixture can be created if the concentration of hydrogen exceeds 4% volume within air.
Ventilation requirements	• The aim of including ventilation in a battery location or enclosure is to maintain a hydrogen concentration in air below the 4% Lower Explosion Limit. • Natural ventilation is considered safe if it maintains the hydrogen concentration below the 4% volume in air limit. • The minimum air flow rate for ventilation of a battery location or enclosure is calculated using the formula provided and defined in this section of the standard.
Natural ventilation	• If natural ventilation can supply the defined amount of airflow defined in the Ventilation requirements section, then it can be considered sufficient. • The air inlet and outlet opening areas can be calculated using the formula provided and defined in this section of the standard. • Additional requirements regarding the positioning of the inlet and outlet are also included.
Forced ventilation	• Where the required airflow cannot be met via natural ventilation then forced ventilation is required to be used.

	• The air extracted from the enclosure shall be exhausted to the atmosphere and an alarm shall be initiated if the required airflow is not met.
Charging modes	• The typical charging mode for stationary batteries is the constant current/voltage charge. • Where other charging methods are used, the ventilation air flow shall be sized according to the maximum charger output current. • Additional requirements are stated for the use of charge equipment with a taper characteristic.
Overcharging under fault conditions	• Since circumstances where the battery may produce more gas than the installed ventilation system can occur, electrical precautions against charging malfunction and thermal runaway shall be provided. • This could include lowering the charge voltage below the open circuit voltage or by automatic disconnection of the charging power supply.
Close vicinity to the battery	• When close to the battery, the sufficient dilution of explosive gasses cannot always be ensured. As a result, a safety distance through air shall be implemented to provide sufficient separation distance between sparking or glowing devices and the gas producing components. • The standard includes and defines a formular to calculate the required separation distance. • Additional requirements are included for systems in which the separation distance may be reduced via more stringent limits on the hydrogen concentration in air.
Prevention of electrostatic discharges when working with batteries	• This section details the requirement to not wear clothes and footwear which may cause the build-up of electrostatic charges. • Battery cleaning material requirements are also included in this section.

Provisions against electrolyte hazards – There are hazards resulting from exposure to acid and alkaline electrolytes, including burns in the eyes and on the skin. A source of clean water shall be provided in the vicinity of the battery for removing electrolyte which has contacted body parts. Specific advice for eye contact and skin contact is provided in this section. Further requirements include the use of materials that are resistant or protected from the chemical effects of the electrolyte for use in items such as battery accessories, battery stands and other components within the battery enclosure.

Accommodation, housing – This section details the requirements for the different types of protective battery accommodations, including separate battery rooms, separated battery areas in electrical accommodation, indoor or outdoor cabinets and enclosures, as well as battery compartments within appliances. These main topics are summarised in Table 3 below. The following factors should be considered when identifying the required type of battery accommodation:

- External hazard protection (e.g. fire, water, vibration, vermin etc.)
- Protection from Hazards that are generated by the battery itself (e.g. high voltage, explosion hazards, electrolyte hazards etc.)
- Protection from access by unauthorised personnel
- Protection from environmental influences (e.g. temperature, humidity etc.)

Table 3: IEC 62485-2 accommodation and housing section content summary

Topic	Aim and content review
Specific requirements for separate battery rooms	• The varying type and size of batteries results in a range of requirements for a separate battery room. • These requirements include restricted access, ventilation requirements, mechanical performance, and electrostatic dissipation (according to IEC 60364-4-41).
Specific requirements for specially separated areas in rooms accommodating electrical equipment	• Additional measures to be applied alongside the specific requirements for separate battery rooms.
Battery enclosures	• This section outlines the reasons why a battery enclosure may be selected. • The requirements to be applied when housing batteries within an enclosure are also detailed in this section.
Working near batteries	• To facilitate activities such as inspection, maintenance, and the changing of cells, this section details working space requirements.
Accommodation of lead-acid and Nickel-cadmium batteries in the same room	• Precautions to avoid the mixing of maintenance tools and electrolyte cross-contaminations are detailed.

Charge current requirements – Specific charging methods and modes of operation are detailed in Annex A of this standard. However, this section does provide general information regarding the superimposed and maximum ripple current, with recommended upper limit values specified for a number of battery chemistries.

Identification labels, warning notices and instructions for use, installation and maintenance – A minimum of the following warning labels or notices (according to ISO 3864) shall identify a battery room and be displayed on the exterior of the enclosure:

- "Dangerous voltage", if the battery voltage is greater than 60V DC
- Barring sign for "Fire, naked flames, smoking prohibited"
- Warning sign "Accumulator, Battery Room"

Furthermore, additional information is included for the specific identification labels that are required on cells or monobloc batteries, with all information stated by the relevant battery standards being included. Alongside these requirements, the instructions for use, installation and maintenance are listed in this section. These must be supplied with the battery and displayed in its vicinity.

Transportation, storage, disposal and environmental aspects – The two following aspects are detailed in this section of the standard:

- Packing and transport
- Dismantling, disposal, and recycling of batteries

Inspection and monitoring – Regular inspection of the battery and the operating environment are required. This section of the standard lists the items that should be included for inspection alongside the need to complete the

inspection in accordance with the manufacturer's requirements. The methods for the completion of capacity tests for a number of specific battery technologies are also listed in this section.

3.1.2.3 NFPA 855 - Standard for the Installation of Stationary Energy Storage Systems

The NFPA 855 standard provides the minimum requirements for mitigating the hazards associated with Energy Storage Systems. Specific requirements for stationary nickel-based battery systems (including RNZB batteries) are included in this standard.

Nickel-based battery systems must comply with requirements concerning the following items:

- Exhaust ventilation
- Spill control
- Neutralization
- Safety caps
- Thermal runaway
- Explosion control
- Size and separation

The following requirements apply to nickel-based batteries:

Table 4: NFPA 855 nickel based ESS safety requirements

Topic	Qualifying batteries	NFPA 855 Requirement
Clearance to exposures	All batteries	• Maximum outdoor walk-in ESS container dimensions. • Outdoor ESS enclosures shall have a set separation distance from items such as buildings, public ways and hazard materials. • Separation distance reduced to 3ft if 1-hour freestanding fire barrier (1.5m above and beyond physical boundary of ESS) is present. • Clearance to buildings reduced to 3ft if compliant. • Exhaust outlets from ESS that exhaust anything other than ventilation air shall have separation distances from HVAC units air intakes, windows, doors, loading docks, ignition sources and other openings into buildings.
Maximum energy stored	All batteries	• There is no limit to the maximum stored energy of nickel-based systems.
Size & separation	All batteries	• ESS comprised of groups with a maximum stored energy of 50kWh each, with each group separated by a minimum distance. • Larger energy capacities and smaller spacing can be approved based on UL 9540A testing.
Exhaust ventilation	Vented RNZB batteries	• Ventilation system designed to limit the maximum concentration of flammable gas to 25% of the lower flammability limit of the total volume of the enclosure housing the battery.

	Vented RNZB batteries	• Ventilation provided at a minimum rate per area of enclosure floor area. • Mechanical exhaust system can be either continuous or activated by gas detection system.
	Vented RNZB batteries	• Enclosures containing ESS shall be protected by approved continuous gas detection systems. • This standard outlines a number of minimum requirements of the gas detection system.
Explosion control	Vented RNZB batteries	• ESS installed within an enclosure shall have an explosion prevention system designed, installed, operated and tested in accordance with NFPA 69. • Such ESS systems shall also have a deflagration venting installed and maintained in accordance with NFPA 68.
	Vented RNZB batteries	• Explosion prevention and deflagration venting shall not be required where approved by the AHJ based on large-scale fire testing that demonstrates that flammable gas concentrations in the unit cannot exceed 25% of LFL in locations where gas is likely to accumulate.
Spill control	Vented RNZB batteries	• Area containing ESS with free-flowing electrolyte require spill control if any of the following conditions are met: ○ Single vessel capacity limit ○ Multiple vessels capacity limit
Neutralization	Vented RNZB batteries	• An approved method to neutralise spills from free-flowing electrolyte shall be provided but is not required for ESS with immobilised electrolyte. • The method shall be capable of neutralising spills from the largest battery or vessel to a pH between 5.0 and 9.0.

3.1.2.4 UL 9540A - ANSI/CAN/UL Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

The UL 9540A standard outlines tests that can be applied to a battery technology to determine its ability to undergo thermal runaway and then evaluate the resultant fire and explosion hazards (if the technology has demonstrated an ability to undergo thermal runaway). This is an important standard for analysing the safety of a battery energy storage system, with the results of these tests used to determine the required fire and explosion protection for the system in question. Any fire protection requirements that are not related to the battery energy storage system equipment will be covered by other appropriate installation codes.

The tests within UL 9540A address multiple key issues:

- BESS installation instructions
- The ventilation requirements of the installation
- The effectiveness of the installed fire protection, including both integral and external protection
- The employed strategy and tactics to be used by the fire service response

The tests are separated based on the system level being tested. These system levels include the cell level, module level, unit level and the installation level. Each level has a range of characteristics that are reported and

performance requirements that are assessed. If performance levels are met, then no further testing is required. However, if the performance level is not met then the further tests at the next level are conducted and reviewed in a similar manner. The final level of testing is at the Installation Level, and is only required if all three prior levels of testing do not pass the stated performance requirements. Furthermore, two annexes are included to provide additional information. Annex A includes details regarding the test methodologies for the different levels of system tested, as well as instructions regarding the evaluation of the test results. Annex B provides safety recommendations for the testing procedure.

The contents included in each of test level sections of the standard are detailed below:

- Cell level contents
  - General
  - Sample
  - Determination of thermal runaway methodology
  - Cell vent gas composition test
  - Off gas composition for flow battery systems
  - Cell level test report
  - Performance – cell level test
  - Performance – flow battery thermal runaway determination tests
- Module level contents
  - Sample
  - Test method
  - Module level test report
  - Performance at module level testing
- Unit level contents
  - Sample and test configuration
  - Test method – Indoor floor mounted BESS units
  - Test method – Outdoor ground mounted units
  - Test method – Indoor wall mounted units
  - Test method – Outdoor wall mounted units
  - Rooftop and open garage installations
  - Unit level test report
  - Performance at unit level testing
- Installation level contents
  - General
  - Sample
  - Test method 1 – Effectiveness of sprinklers
  - Installation level test report – Test method 1 – Effectiveness of sprinklers
  - Performance - Test method 1 – Effectiveness of sprinklers
  - Test method 2 – effectiveness of fire protection plan
  - Installation level test report – Test method 2 – effectiveness of fire protection plan
  - Performance – Test method 2- Effectiveness of fire protection plan

Table 5: Reported information and performance requirements of UL 9540A sections

Section of UL 9540A	Reported information in section	Main performance requirements
Cell level	• Cell design • Thermal runaway methodology • Cell surface temperature at gas venting • Cell surface temperature at thermal runaway • Gas composition and Lower Flammability Limit, burning velocity and maximum power.	• Thermal runaway cannot be induced in a cell • The cell vent gas is non-flammable in air. In accordance with ASTM E918, which is a standard that outlines the standard practice for determining the limits of flammability of chemicals and elevated temperatures and pressures. • If these requirements are satisfied, then no further testing is required. If these requirements are not satisfied, then Module level testing is required.
Module level	• Module design • Heat release rate • Gas generation and composition • External flaming and flying debris hazards	• The effects of a thermal runaway event are contained by the module design employed by the battery system. • Cell vent gas, based on the results of the cell level tests, are not flammable. • If these requirements are satisfied. then no further testing is required. If these requirements are not satisfied, then Unit level testing is required.
Unit level	• BESS design • Heat release rate • Gas generation and composition • Deflagration and flying debris hazards • Target BESS and wall surface temperature • Heat flux at target walls, BESS and means of egress • Reignition	• The target BESS temperature is less than the cell surface temperature at gas venting and meets the heat flux limits for means of egress. • The temperature increase of the target walls is less than 97°C. • No explosion hazards exhibited by the product. • No flaming beyond the outer dimensions of the BESS unit. • If these requirements are satisfied. then no further testing is required. If these requirements are not satisfied, then Installation level testing is required.
Installation level	• Fire protection equipment • Target BESS and wall surface temperature • Gas generation and composition • Deflagration and flying debris hazards • Heat flux at target walls • Reignition	• The target BESS temperature is less than the gas venting temperature measured in the cell level testing. • The temperature increase of the target walls is less than 97°C. • The flame indicator shall not propagate flames beyond the width of the initiating BESS. • No flaming outside of the test room and the heat flux limits for means of egress are met.

3.1.2.5 IEC 62933-5-1 - Electrical energy storage (EES) systems - Part 5-1: Safety considerations for grid-integrated EES systems - General specification

This section of the IEC 62933 standard provides the technical specification of safety aspects which are required for electrical energy storage systems which are to be used for grid-connected applications. These specifications include hazard identification, the assessment of relevant risks, and the required risk mitigation actions. The Hazard identification section of this document outlines the electrical, mechanical, and other additional hazards that apply to electricity grid connected ESS systems.

A detailed ESS system risk assessment section provides an overview of specific and general characteristics of the ESS system structure relevant to the risk assessment process. Furthermore, multiple storage system conditions are explored, including the types of grid and storage applications available, the location of the EES system, the vulnerable EES system elements, and potential sources of external aggression. The procedure for analysing identified risks is also provided, with sections covering risk considerations and risk level analysis.

This section of the IECC 62933 standard states the requirements necessary to reduce the identified risks within an EES system. These requirements include the following points:

- General risk reducing measures
- Preventative measures to reduce the risk of damaging neighbouring inhabitants
- Preventative measures against damaging workers and residents
- Over current protection design
- Disconnection and shutdown of the EES system
- Preventative maintenance
- Staff training
- Safety design

3.1.2.6 IEC 62933-5-2 - Electrical energy storage (EES) systems - Part 5-2: Safety requirements for grid-integrated EES systems - Electrochemical-based systems

This section of the IEC 62933 standard focusses on the safety aspects for people for grid-connected electrochemical energy storage systems. Safety matters regarding the surroundings and other living beings are also included. The entire life cycle of the BESS is applicable to this safety standard. This document expands on the requirements outlined in IEC 62933-5-1 to consider the additional safety requirements required due to the use of an electrochemical storage subsystem within an energy storage system. Basic safety guidelines relevant to BESS are also detailed. Annex B.5 reviews the commercially available battery technologies, including section B.5.4, which focusses on Nickel based batteries.

In addition to the hazard risk assessment details included in IEC 621933-5-1, this document provides details regarding BESS specific assessment. The specific and general characteristics of BESS structure are outlined, as well as the relevant BESS specific risk analysis procedures that are required.

Alongside the requirements necessary to reduce risks provided in IEC 62933-5-1, this document adds additional details relevant to BESS. These include the general requirements needed for BESS safety, as well as items regarding the inherently safe design of battery energy storage systems. These items include:

- Protection from electrical and mechanical hazards
- Protection from explosion
- Protection from the hazards arising from electric, magnetic, and electromagnetic fields

- Protection from fire hazards
- Protection from temperature hazards
- Protection from chemical effects
- Protection from hazards arising from auxiliary, control, and communication system malfunctions
- Protection from hazards arising from environments

For each of these items, this document also provides details regarding the system validation and testing that is required.

3.1.2.7 UL 2436 - UL LLC Outline of Investigation for Spill Containment for Stationary Acid and Alkaline Electrolyte Battery Systems

This UL standard outlines the requirements that over the containment of spillages from stationary acid and alkaline electrolyte battery systems. This standard aims to provide a means of containing the hazardous material liquids that are exposed in the event of an electrolyte leakage from battery systems, including nickel-based systems.

The main items investigate in this standard include the liquid tightness of the battery system, the level of electrolyte absorption, the capability for the pH neutralisation of the spilled liquids, and the resistance to the potential spread of flames.

This standard provides construction requirements that outline the suitable materials for use in battery systems with acid and alkaline electrolytes, as well as spill containment measures and electrolyte absorption and neutralisation construction requirements. Furthermore, both system and material level tests are outlined in UL 2436 to assess the suitability of these components for the intended use case.

The system level tests include:

- Leakage testing
- Electrolyte absorption level tests
- Tests to estimate the neutralisation capability of the system

The material tests include:

- Penetration resistance test
- Volume change and extraction of soluble material test
- Air oven ageing test
- Immersion test
- Rigid plastic test
- Flexural strength test
- Joint strength test
- Non-rigid plastic test
- Tensile strength and elongation test
- Tear strength test
- Seam strength test
- Tensile impact test
- Fire resistance test

Furthermore, this standard includes the specific marking requirements of stationary battery systems containing acid and alkaline electrolyte. These include the required cautionary markings, the nameplate markings, and other non-

cautionary markings to be included. Instructions for the installation, maintenance and neutralising units are also detailed in this document.

3.1.2.8 Additional safety standards for reference

- UL 2054 – UL Standard for Household and Commercial Batteries
- UL 1989 – UL Standard for Safety Standby Batteries
- UL 1778 – UL Standard for Safety Uninterruptable Power Systems

3.1.3 Performance requirements

3.1.3.1 IEC 61427-1 - Secondary cells and batteries for renewable energy storage — General requirements and methods of test - Part 1: Photovoltaic off-grid application

This component of the IEC 61427 standard covers the general requirements for secondary batteries used in photovoltaic energy systems and the methods of tests used to verify the performance of such batteries.

The following types of secondary batteries and cells are mainly used in photovoltaic energy systems:

- Vented (flooded)
- Valve-regulated
- Gastight sealed

A number of general operating conditions are stated which cover the typical use of secondary battery systems utilised by photovoltaic energy systems. These operating conditions include:

- Autonomy time
- Typical charge and discharge currents
- Daily cycles
- Seasonal cycles
- Periods of high state of charge
- Periods of sustained low state of charge
- Electrolyte stratification
- Storage
- Operating temperature
- Charge control
- Physical protection

Alongside the general operating conditions of the secondary cells and batteries, this standard also contains a number of general performance requirements. These performance requirements are outlined in Table 6, below.

Table 6: IEC 61427-1 General battery performance requirements

Topic	Requirement details
Mechanical endurance	• Batteries for photovoltaic applications shall be able to withstand the mechanical stresses occurring during transportation and installation. • Additionally, case specific requirements are individually specified or referred to in a relevant standard.

Charge efficiency	• The charging efficiency (ratio between the quantity of electricity delivered during discharge and the quantity of electricity necessary to restore the initial state of charge) is specified for a range of battery state of charges (SoCs). • These values are provided for a number of different cell chemistries.
Deep discharge protection	• Specific requirements for lead acid and vented and partial gas recombination Nickel-cadmium batteries. • For other battery chemistries, manufacturer's recommendations are to be followed.
Marking	• Marking of the cells or batteries shall follow the outlined requirements in section 7.2 of this standard.
Safety	• Manufacturer's instructions and any applicable local regulations shall be followed during transport, installation, commissioning, operation, maintenance, decommissioning and disposal.
Documentation	• The manufacturer shall provide documentation for transport, installation, commissioning, operation, maintenance, decommissioning and disposal of cells and batteries for photovoltaic applications.

This standard also outlines the functional characteristics by which batteries for use in photovoltaic applications shall be characterised. These include:

- Rated capacity
- Endurance in cycling
- Charge retention
- Endurance in cycling in photovoltaic applications (extreme conditions)

The details of each of the functional characteristics listed above are included in the test methods section of this standard.

3.1.3.2 IEC 61427-2 - Secondary cells and batteries for renewable energy storage — General requirements and methods of test - Part 2: On-grid applications

This component of the IEC 61427 standard covers the usage of secondary batteries for on-grid electrical energy storage applications. The required battery properties, endurance, and electrical performance, as well as the associated testing methods to review these characteristics are outlined. These test methods outlined are battery chemistry agnostic and can be applied to all types of secondary batteries. The on-grid application specified in this standard is defined by the fact that the batteries are connection, via power conversion devices to an electricity grid (of varying potential size and scope) to provide a range of services. These services include acting as an instant energy source or sink to stabilise gird performance with connected renewable energy sources. IEC 61427 does not cover related power conversion and grid interface equipment. A comprehensive list of terms and definitions is provided in the standard document for reference.

Due to the characteristics of renewable energy sources (high intermittency and low predictability), transmission and distribution grids can be subjected to instability conditions and overload. It is therefore required to use energy storage devices, such as grid-connected batteries to temporarily store surplus energy and release it in a controlled manner to smooth and stabilise the flow of power in a grid system. This section of the IEC 61427 standard provides tests to quantify the capabilities of batteries with different chemistries and designs for grid-connected applications.

This section of the IEC 61427 standard includes a number of tables to report the battery properties and electrical performance.

The following tables are used to report the key features of the full-sized battery and test object battery, as available from the manufacturer or via experimental determination:

- Table 1 – Summary of endurance test related electrical property data for full-sized battery and the test-object battery.
- Table 2 - Summary of the physical dimension data of the full-sized battery.
- Table 3 – Summary description of the full-sized battery
- Table 4 – Summary description of the test-object battery

The determination of energy content and discharge performance of the test-object battery (thermally equilibrated) is reported in:

- Table 5 – Summary of the constant power discharge performance of the test-object battery of 25°C ± 3 K

The determination of the energy efficiency during endurance tests is cogenerated with the endurance tests and reported in:

- Table 6 – Summary of energy efficiencies determined in endurance tests at an ambient temperature of 25°C ± 3 K

The determination of the energy efficiency during endurance tests at the minimum and maximum ambient temperature is cogenerated with the endurance tests and reported in:

- Table 7 – Summary of the energy efficiencies determined in endurance cycle tests at the minimum and maximum ambient temperature
- Table 8 – Parameters to achieve and maintain the target operational state of charge during tests at the minimum ambient temperature
- Table 9 – Parameters to achieve and maintain the target operational state of charge during tests at the maximum ambient temperature

The determination of waste heat generated during endurance tests at the maximum ambient temperature is reported in:

- Table 10 – Summary of the energy released as heat during endurance tests at the maximum ambient temperature

The determination of energy requirements during periods of idle state at 25°C ambient is reported in:

- Table 11 – Summary of energy required during idle state periods at 25°C ± 3 K ambient temperature

3.1.3.3 IEC TS 62933-3-1 - Electrical energy storage (EES) systems Part 3-1: Planning and performance assessment of electrical energy storage systems - General specification.

This section of the IEC 62933 standard is applied to electrical energy storage systems that are designed for either indoor or outdoor installations for grid-connected applications. A wide range of performance topics are covered in this document. The general structure of an electrical energy storage system is detailed, including the system architecture and specifications of subsystems, including the accumulator, power conversion, auxiliary and control subsystems.

The planning requirements for electrical energy storage systems are also detailed, with specific attention paid to the planned system environment and application sizing considerations. The main electrical parameters of the system are provided and include the following:

- Input and output power rating
- Rated energy capacity
- Auxiliary power consumption
- Self-discharge
- Roundtrip efficiency
- Duty cycle roundtrip efficiency
- Recovery times
- End-of-service life values

Furthermore, control metrics related to the functional system performance are also outlined in this section of the IEC 62933 standard, as well as communication interface details.

The assessment of the electrical system performance for grid-connected applications is divided into four distinct sections, Factory Acceptance Tests, installation and commissioning phases, Site Acceptance Tests, and the performance monitoring phase. The included annexes in this document provide examples of electrical energy storage systems designed for different grid-connected applications. These include:

- ESS systems designed for reserve control
    - Primary frequency control
    - Secondary frequency control
    - Dynamic frequency control
- ESS systems to be used alongside renewable energy production
    - Renewable energy firming
    - Renewable energy smoothing
- ESS systems to be used to support the grid
    - Grid voltage support
    - Power quality support via voltage-regulated active power injection

3.1.4 Main EU recycling legislation

3.1.4.1 DIRECTIVE 2006/66/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

The main objective of this Directive of the European Parliament and of the Council is to take necessary measures to maximise the separate collection of waste batteries and accumulators, minimising the disposal of these items as mixed municipal waste and achieve a high level of recycling of all waste batteries and accumulators. This directive is applicable to all types of batteries and accumulators.

Two key prohibitions are detailed in this directive, limiting the percentage weight of the following materials:

- All batteries and accumulators shall not contain more than 0.0005% of mercury by weight
- Potable batteries and accumulators shall not contain more than 0.002% of cadmium by weight

Batteries and accumulators that are non-compliant with these requirements shall be prohibited by member states from being placed on the market.

This directive contains articles regarding the implementation of the directive. Table 7 below provides a summary of relevant articles:

Table 7: Summary of relevant article requirements in Directive 2006/66/EC

Article name	Summary of article requirements
Article 8: Collection schemes	• Member states are required to ensure to collection schemes are in place for waste portable batteries and accumulators. These schemes must provide accessible collections points for end-users, require distributors to receive waste batteries and accumulators at no charge, and shall not charge the end-users. • Member states may require producers to set up collection schemes. • The producers of industrial batteries and accumulators shall be held accountable to take back waste industrial batteries and accumulators by member states.
Article 10: Collection targets	• Member states shall achieve a minimum collection rate of 45% by September 2016 • Annex I is provided in the directive to detail the monitoring of member states collection rates
Article 11: Removal of wate batteries and accumulators	• Manufacturers are required to design appliances in such a way that batteries and accumulators can be readily removed. This is to be ensured by member states. • Instructions shall be provided with appliances in which batteries and accumulators are integrated.
Article 12: Treatment and recycling	• Producers and third-parties are to set up schemes (using the best available techniques) to provide for the treatment and recycling of wate batteries and accumulators. Member states are required to ensure this. • All batteries and accumulators that are collected in accordance with article 8, undergo treatment, or are recycling, shall comply with Community legislation (with a focus on health, safety and waste management). • Minimum treatment requirements are detailed in Annex III, Part A • When collected with electronic equipment, batteries and accumulators shall be removed. • Recycling processes must meet the efficiencies and provisions provided in Annex III, Part B
Article 15: Exports	• Treatment and recycling can be completed outside of the Community/member state. This must be done in compliance with Council Regulation (EEC) No 259/93 with regards to shipping.
Article 16: Financing	• Producers, or third-parties acting on their behalf, shall finance any net costs arising from the collection, treatment and recycling of all waste portable batteries and accumulators (which have been collected as stipulated in Article 8). They shall also finance the collection, treatment and recycling of all waste industrial and automotive batteries and accumulators (which have been collected as stipulated in Article 8). • Producers and users of industrial or automotive batteries and accumulators may conclude agreements stipulating financing arrangements other than the ones described above.
Article 18: Small producers	• Producers that are small relative to the size of the national marketplace may be made exempt by the member states. However, this must not impede the proper functioning of the collection and recycling schemes.
Article 21: Labelling	• A number of labelling requirements are outlined in this article, and are to be applied to all batteries, accumulators and battery packs. • Annex II also provides references to the marking symbols.

The directive also contains the following Annexes:

- Annex I: monitoring of compliance with the article 10 collection targets
- Annex II: symbols for batteries, accumulators and battery packs for separate collection
- Annex III: detailed treatment and recycling requirements
- Annex IV: procedural requirements for registration

Table 8 below summarises the requirements included in Annex III:

Table 8: Summary of Annex III in Directive 2006/66/EC

Annex Part	Summary of requirements
Part A: Treatment	• As a minimum requirement, treatment of batteries and accumulators shall include the removal of all fluids and acids. • Treatment (and any potential temporary storage) of batteries and accumulators shall take place in sites with impermeable surfaces and suitable weatherproof coverings (or in suitable containers).
Part B: Recycling	• A number of minimum recycling efficiencies are provided regarding recycling processes. These are as follows: ○ Recycling of 65% (by average weight) of lead-acid batteries and accumulators. This also includes recycling of the lead content to the highest degree that is technically feasible while avoiding excessive costs. ○ Recycling of 75% (by average weight) of nickel-cadmium batteries and accumulators. This also includes recycling of the cadmium content to the highest degree that is technically feasible while avoiding excessive costs. ○ Recycling of 50% by average of other wate batteries and accumulators.

3.1.4.2 IEC 61429 - Marking of secondary cells and batteries with the international recycling symbol ISO 7000-1135

This European Standard outlines the identification requirements of certain secondary batteries that are legally required to be kept separate from normal waste disposal and returned to recycling facilities. The conditions of utilisation of the International Organisation for Standardization recycling symbol are defined in this standard. This standard is applicable to both lead-acid and nickel-cadmium batteries.

It is required that cells are marked individually, except for those that are part of a battery or battery subassembly that cannot be dismantled. The specific requirements regarding the sizing of the symbol and its location on the cells or batteries (or on the packaging of button cells) are included in this standard.

3.1.5 Standard tests that the battery must complete

3.1.5.1 UL 1973 - ANSI/CAN/UL Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications

The UL 1973 standard covers the requirements for electric energy storage systems for use in Stationary and Light Electric Rail applications. The stationary applications considered by this standard include, but are not limited to,

energy storage co-location with PV or wind turbines and for uninterruptable power systems (UPS). This standard outlines the construction requirements for stationary battery systems, as well as performance requirements in the form of electrical, mechanical, and environmental tests that must be completed. Furthermore, requirements for the marking of batteries intended for the aforementioned use cases are also included in this standard.

This standard applies to all electric energy storage systems that are intended for stationary applications or use in Light Electric Rail applications. This includes the use of RNZB battery systems in stationary storage applications.

There are a number of requirements for the performance of the electrical, mechanical and environmental tests detailed in this standard. These are outlined in the Table 9 below:

Table 9: Test performance requirements of UL 1973

Performance topic	UL 1973 Requirements
General test requirements	• Unless otherwise stated the device under test shall be at the maximum operational start of charge. • Specified battery sample criteria. • Specified sample resting times after charging and prior to testing. • Test ambient temperature requirements. • Thermal equilibrium conditions to be applied
Determination of potential for fire hazard	• Visible signs of fire to be identified. Non-compliance results shall also include an evaluation for potential flammable concentrations of vapours during testing. • A gas monitor suitable for detecting 25% of the Lower Flammability Limit will be used to identify potential flammable concentrations of gas emitted during tests. • A minimum of 2 sampling locations where gas concentrations may occur shall be sued to take measurements.
Important test considerations	• The tests in this standard may result in explosions, fire and emissions of flammable and/or toxic fumes, leakage of hazardous chemicals as well as electric shock. • Protective measures include protective equipment well ventilated areas and a suitably designed test facility.
Single fault conditions	• Where there is a specific reference to a single fault condition in the individual test methods, the single fault is to consist of a single failure (i.e. open, short of other failure means) of any component in the ESS that could occur as identified in the system safety analysis.
Determining of toxic emissions	• The following sampling methods shall be implemented when toxic gasses are vented from cells/capacitors: ○ ASTM D4490 ○ ASTM D4599 ○ OSHA Evaluation Guidelines for Air Sampling Methods Utilising Spectroscopic Analysis ○ NIOSH Manual of Analytic Methods
Measurement equipment accuracy	• The following measurements have required accuracy values within this standard: ○ Voltage +/- 1% ○ Current +/- 3% ○ Watts +/- 4% ○ Temperatures +/- 2 °C

	○ Time +/- 0.1% ○ Dimensions +/- 1% ○ Ah +/- 3% ○ Wh +/- 4%

The required electrical tests are outlined in Table 10 below. Non-compliant test results include the following test outcomes:

- Explosion
- Fire
- Combustible vapour concentrations
- Toxic vapour release
- Electric shock hazard
- Leakage external to the enclosure of the device under test
- Rupture of the device under test resulting in the exposure of hazardous parts
- Loss of protection controls

Table 10: Electrical tests required by UL 1973

Electrical test	Test aim and evaluation
Overcharge test	• To evaluate the ability of the energy storage systems to withstand an overcharge condition. • A fully discharged device is subjected to an overcharge resulting from a single fault condition to examine the functionality of the protective circuitry. • ESS failure is evidenced by explosion, fire or other non-compliant results.
Short-circuit test	• This test examines a fully charged device under test's (DUT's) ability to withstand an external short circuit (connecting the positive and negative terminals of the battery with a resistive circuit load having a maximum total resistance of 20mΩ). • At the conclusion of the test and observation period the sample is subjected to an 'as received' dielectric voltage withstand test. • The DUT is examined for signs of rupture of leakage, as well as signs of other non-compliance results.
Over discharge protection test	• The DUT's ability to withstand an over discharge condition is examined in this test. This includes all discharge protection circuitry for both the temperature and minimum voltage. • The DUT is subjected to constant current/power discharge at the manufacturer's maximum discharge rate, continuing until one of the following conditions is met: ○ The passive protection device(s) activate ○ The minimum cell voltage is reached ○ The maximum cell temperature is reached. ○ DUT has been discharged for an additional 30 min after it has reached its specified normal discharge limit • During the test and throughout an observation period the DUT is examined for any non-compliance conditions.
Temperature and operating limits check test	• The DUT is tested to ensure it remains within its specified operating limits (voltage and current at a specified temperature) during maximum charge and discharge conditions.

	• This test also determines whether other temperature sensitive critical components are maintained within the specified temperature ratings based on the maximum operating temperature specifications of the DUT. • During this test, the manufacturer's specified operating limits (voltage and current at specified temperatures) shall not be exceeded during the test charge and discharge cycles. Furthermore, temperatures measured on the DUT components shall not exceed their specifications, or any other non-compliance results be observed.
Imbalance charging test	• This test determines whether an ESS with series connected cells or modules can maintain the cells or modules within their specified operating parameters if they become imbalanced. • This is done by fully discharging a DUT (bar one cell/module which is maintained at 50% SoC to create an imbalance), before charging the sample in accordance with the manufacturer's maximum normal charging specifications. • The voltage of the partially charge cell/module is monitored during charging to determine if it's voltage limits are exceeded. After the DUT is charged, it is also subjected to another discharge and charge cycle to the manufacturer's specifications and the sample is observed. • The maximum voltage limit of the partially charged module shall not be exceeded when the imbalanced DUT is charged, and other non-compliance results are monitored.

Dielectric voltage withstand test	• This test evaluates the electrical spacings and insulation of hazardous voltage circuits within the electrical energy storage system.
	• Circuits that exceed 24.4V peak of 60V DC shall be subjected to an electric strength test in accordance with UL 60950-1 Clause 5.2 requirements.
	• This test involves test voltage being applied (for a minimum of 1 minute) between the hazardous voltage charging circuit and:
	  ○ Enclosure/accessible non-current carrying conductive parts
	  ○ Non-current carrying conductive parts that may be accessible
	• The test is failed if accessible parts of the DUT with insulating material become live in the event of an insulation fault.
	• There shall also be no evidence of dielectric breakdown.

Continuity test	• The continuity of the protective grounding and bonding system of the electric energy storage system is evaluated in this test. • The resistance of the grounding system shall be <0.1Ω between any two parts of the system that are measured with the continuity test. • This value is calculated using the measured voltage droop and current after applying test currents of 200% of the rating of the overcurrent protection device for a period of 200% of the time-current characteristic of the overcurrent protection device.
Failure of the cooling or thermal stability system	• The purpose of this test is to determine if the electrical energy storage system can safely withstand a failure in the cooling or thermal stability system. • A prepared DUT is charged at max rate with the cooling system disabled whilst within a conditioning chamber. The same process is completed by discharging a fully charged DUT.

	• The DUT is observed for non-compliance conditions and subjected to a discharge/charge cycle if operational after the test is completed.

Working voltage measurements	• This test measures the working voltage of an electric energy storage system.
	• This working voltage is measured between:
	  ○ Live parts of opposite polarity
	  ○ Live and dead metal parts
	  ○ Live parts and a metal enclosure
	  ○ Live and ground connections under both normal charging and discharging conditions
	  ○ The values obtained for the working voltage are used to verify the electrical spacing criteria.

The required mechanical tests are outlined in Table 11 below. Non-compliant test results include the following test outcomes:

Table 11: Mechanical tests required by UL 1973 (not including LER application specific tests)

Mechanical test	Test aim and evaluation
Static force test	• The purpose of this test is to determine if the enclosure has sufficient strength to safely withstand an applied static force of 250N +/-10N for 5s. • A circular contact plane of 30mm diameter is used to apply the force. • After observation period the DUT shall be subjected to an 'as received' dielectric voltage withstand test. • The DUT is examined for signs of rupture and evidence of leakage, as well as a number of other non-compliance results.
Impact test	• The purpose of this test is to evaluate the mechanical integrity of the enclosure and its ability to provide mechanical protection to ESS contents. • A fully charged DUT is subjected to a minimum of 3 impacts of 6.8J, with the impact produced by dropping a steel sphere (50.87mm diameter) from a height of 1.29m onto the enclosure. • An image of the test setup is provided in the standard. • After observation period the DUT shall be subjected to an 'as received' dielectric voltage withstand test. • The DUT is examined for signs of rupture and evidence of leakage, as well as a number of other non-compliance results.

Drop impact test	• This test is designed to evaluate battery modules that are intended for field installation into rack mounted equipment. These modules are subjected to a drop impact test to determine that no hazards exist as a result of an accidental drop during the battery installation process.
	• The following drop heights are utilised in this test:
	  ○ Product < 7kg results in a minimum drop height of 100cm
	  ○ 7kh < Product < 100kg results in a minimum drop height of 10cm
	  ○ Product > 100kg results in a minimum drop height of 2.5cm
	• The impact position should occur in the position most likely to produce adverse effects.

	• The sample should be dropped a minimum of 1 time, and at least 1 test must not be a 'flat drop'. • The DUT is subjected to a charge/discharge cycle, a dielectric voltage withstand test and then an observation period. Non-compliance results are evaluated.
Additional tests	The UL 1973 standard also contains a number of tests for other components: • Wall mount fixture/handle test • Mould stress test • Pressure release test • Start-to-discharge test

The UL 1973 standard also includes a number of environmental tests which are outlined in Table 12 below.

Table 12: Environmental tests required by UL 1973

Environmental test	Test aim and evaluation
Thermal cycling test	• Only applicable to Light Electric Rail applications
Resistance to moisture test	• The purpose of this test is to ensure that the energy storage system can withstand in a safe manner, exposure to moisture levels that are likely to occur during the end use case. • The DUT is tested based on its allocated IP rating in accordance with ANSI/IEC 60529. • During and after the test the DUT is observed for signs of non-compliance conditions.
Salt fog test	• Energy storage systems designed for use near marine environments are subjected to this test which determines the ability of the system to safely withstand exposure to salt fog conditions. • A fully charged electrical storage system is subjected to the test methods outlined in IEC 60068-2-52. • If the DUT is operational after the test is finished, it is subjected to a full discharge and charge cycle in accordance with the manufacturer's specifications. • During the test and during an observation period the DUT is observed for signs of non-compliant results.
External fire exposure test	• This test evaluates the electrical energy storage systems ability to withstand exposure to a hydrocarbon pool/brush fire, including resultant projectiles breaking through the test cage. • A fully charged DUT is subjected to a hydrocarbon pool fire for 20 minutes. Further test specifics and a test set-up diagram are detailed in the standard document. • The test shall not result in a DUT explosion event that results in projectiles falling outside of a perimeter boundary as described in the standard document.
Internal fire exposure test	• The electric energy storage system under test shall be designed to prevent a single cell failure due to thermal runaway cascading throughout the system. • This test is specific to secondary lithium and sodium sulphur battery technologies.

A number of marking requirements are detailed in the UL 1973 standard document. The standard states that these markings shall be permanent in nature, including methods such as ink stamping, engraving and adhesive labels (that are compliant to IL 969). All markings should be visible upon installation of the electric energy storage system. These markings are subjected to a number of other requirements, including:

- Nameplate markings are required, including the manufacturer's name, trade name, trademark or other markings to identify the organisation responsible for the product. The part number (or model number), electrical ratings in volts dc, capacity in Ah or Wh and the battery chemistry are also required. Both storage system terminals should also be marked to indicate whether they are positive or negative.
- The date of manufacture.
- Any electric energy storage systems that are intended for use with specific chargers shall be marked accordingly.
- IP rating code if the storage system is evaluated for protection against ingress of moisture.
- Cautionary markings indicating to read all of the relevant instructions before installation, operation and maintenance of the system.
- Systems required to operate in specific orientations shall be marked accordingly.
- Systems shall be marked with warning marking that indicates the risk of electrocution near battery terminals with hazardous voltage levels.
- Systems which have replaceable fuses shall be marked with the type of fuse for replacement and the relevant rating of the fuse.
- Any separate accessories that are intended for connection to the main supply shall be marked with the manufacturer's name, part number and electrical ratings including voltage, frequency, phase (if applicable) and current or watts.
- A ground terminal shall be marked.
- Additional markings for electrical energy storage systems which are located in restricted access locations. Warnings such as hazardous moving or electrical parts, hot surfaces etc shall be included.

The UL 1973 standard also outlines the requirements for components of an electric energy storage system to be provided with a complete set of instructions for the proper installation of the system and include normal operating specifications. These shall also include any other instructions for electric energy storage systems for installation in a restricted access location, defining the type of location required, its restrictions, signage and any other relevant information. The system shall also be provided with a maintenance manual, with included schedule for maintenance of the system and relevant accessories. Safety precautions regarding the handling or conducting maintenance of the system and its relevant accessories shall also be included.

The following manufacturing and production line tests are stated in the UL 1973 standard:

- Electric energy storage systems to be subjected to 100% production screen to ensure that active safety controls are functioning correctly.
- Dielectric voltage withstand test outlined in the Electrical Tests section of the standard document.
- Continuity check of the grounding.
- Pressure-relief valve start-to-discharge pressure rating test.

The UL1973 appendices cover the following topics:

- Appendix A – List of standards for components
- Appendix B – Test programs for sodium-beta battery cells
- Appendix C – Test program for flowing electrolyte batteries
- Appendix D – Metal compatibility table

- Appendix E – Alternative cell test program

3.1.5.2 ANSI/CAN/UL 9540 – Energy Storage Systems and Equipment

The requirements in this standard cover energy storage systems that are intended to receive electric energy and then store it for later provision to loads or the local/area power system up to the utility grid. This standard covers electrochemical, chemical, mechanical and thermal energy storage devices, as well as additional system equipment for (including but not limited to) charging, discharging, control protection, power conversion, communication, fire detection and suppression. This standard outlines the construction requirements for such energy storage systems, as well as requirements in the form of electrical, mechanical, and environmental tests that must be completed. Only items relevant to electrochemical storage systems have been reviewed in this section.

Table 13: UL 9540 construction requirements

Construction item	UL 9540 requirements
Non-metallic materials	• Stated minimum performance requirements of polymeric materials employed for enclosures of electrical equipment. • Mechanical strength considerations for non-metallic materials for use in enclosures. • Materials for use as electrical insulation shall be resistant to deterioration that would result in an electrical shock, fore, or other safety hazard. • Gaskets and seals relied upon for safety shall be determined suitable for the use case environment conditions and anticipated chemical substance exposure.
Metallic parts resistant to corrosion	• Metallic enclosures shall be corrosion resistant to prevent deterioration that would affect the ability of the enclosure to provide physical protection to end electrical energy storage system or access to hazardous parts.
Enclosures and guarding of hazardous parts	• The enclosure(s) of energy storage systems shall have the required strength and rigidity to resist the possible physical abuses expected during transport, installation, and usage. • Enclosure openings of electric energy storage systems shall be designed to prevent inadvertent access to hazardous parts.
General electrical safety and walk-in systems	• Requirements for worker safety when working in, on or adjacent to the energy storage system. • Design requirements for the access point, workspace and access to hazardous parts within the enclosure. Further design requirements include lighting, ventilation, alarm circuits, water/condensation protection as well as information and markings.
Wiring and electrical supply connections	• Wiring insulation requirements are outlined based on the usage and conditions of the equipment. • Requirements regarding the wiring methods, rating, sizing, routing, support and termination are also included in this section.

General electrical service equipment	• This section outlines the requirements for a number of electrical components, including:
	  ○ Fuses
	  ○ Manual disconnects
	  ○ Circuit breakers
	  ○ Transformers

Electrical spacings and separation of circuits	• This section details the requirements for electrical separation of components within an electrical energy storage system. The following parts are provided spacing requirements based on the relevant voltage: ○ Live parts and dead metal parts that are separated by functional or basic insulation ○ Accessible dead metal parts and dead metal parts separated from live parts by basic insulation only ○ Live parts or accessible dead metal parts separated by double insulation or by reinforced insulation ○ Between any uninsulated live part and an uninsulated live part of opposite polarity, an uninsulated grounded part other than the enclosure, or an exposed metal part (basic insulation) ○ Between any uninsulated live parts and the walls of a metal enclosure, including fittings for conduit or armoured cable (basic insulation)
Insulation levels and protective grounding	• Hazardous voltage circuits require insulation from accessible conductive parts and safety extra low voltage circuits using the following: ○ Basic insulation ○ A system of double or reinforced insulation ○ A combination of both of the above • This section also defines a number of grounding requirements for energy storage systems containing hazardous voltage circuits.
Safety analysis and control systems	• This section details the requirements of the safety analysis which must be conduction for energy storage systems. This includes, but is not limited to, a FMEA analysis to identify critical safety components and circuits, which should be conducted by the manufacturer or integrator of the energy storage system. • Guidance for the analysis is provided in the following standards: ○ IEC 60812 ○ IEC 61025 ○ MIL-STD-1629A • Safety critical electrical and electronic controls of the energy storage system must also comply with appropriate safety standards. Compliance can be demonstrated through evaluation of the following standards: ○ UYL 991 ○ UL 1998 ○ CAN/CSA-E60730-1 ○ IEC 61508 (all parts)
Remote controls	• This section details the requirements for energy storage system remote controls and the ability to disconnect the system from the remote control.
Communications systems	• The installation and operation instructions of the energy storage system shall identify the communications protocols used to communicate between external; systems intended to be connected to the energy storage system
Heating and cooling systems	• This sections details that the upon the failure of the thermal management system, energy storage systems that rely upon integral thermal management systems shall be able to safely shutdown and not result in a hazardous situation.
Piping systems, pressure vessels,	• Piping systems utilised to carry fluids in energy storage systems must comply with one of a number of Piping codes as applicable:

fuel and other fluid supply connections and controls	○ ASME B31 ○ CSA B51 ○ CSA B52 ○ CSA Z662 ○ CSA B149.1 • Pressure vessels and related equipment shall comply with CSA B51. • ASME 31 is applied to the connections of any flammable fuel supplies. • Further requirements for process gas backflow, water contamination, fluid leakage, the rating of manual shut off valves and pressure regulators.
Containment of moving parts	• Only applicable to energy storage systems with the capacity to store kinetic energy.
Hazardous fluid containment	• This section details the requirements for provisions for containment and/or neutralisation of hazardous liquid spills, as well as the prevention of hazardous toxic vapour concentrations and conductive fluids near hazardous voltages.
Combustible concentrations	• There are required ventilation characteristics for energy storage system enclosures containing flammable fluid systems or batteries that vent hydrogen to the atmosphere. • Specific requirements also apply to battery systems that vent hydrogen gas due to electrolysis of aqueous electrolytes. Enclosure openings and ventilation shall prevent concentrations greater than 25% of the lower flammability limit of hydrogen. • This section details the calculation requirements of the minimum ventilation opening area, as well as additional standards that specify the suitability of equipment and electrical components for use within system enclosures.
Fire detection and suppression	• The type and level of the fire detection and suppression system is determined by the fire risk analysis. Guidance on fire risk analysis is provided in NFPA 551 and NFPA 550.
Utility grid interaction	• This section details the requirements for energy storage systems intended for connection with the electric power system/utility grid to export energy. The products outlined in this section include utility-interactive inverters, grid support utility-interactive inverters and special purpose utility-interactive inverters. • The standards that apply to these categories of inverter are detailed in this section.
Energy storage system technologies	• The relevant content in this section includes details regarding electrochemical energy storage systems. Such electrochemical energy storage systems, which are to be used in light electric rail and stationary applications shall comply with the UL 1973 standard. • UL 1973 includes testing and evaluation of the energy storage system, as well as the battery management system.

The UL 9540 standard also contains several electrical, mechanical, environmental, and manufacturing/production tests relevant to energy storage systems. These include the following:

- Electrical tests
  - Normal operations test
  - Dielectric voltage withstand test
  - Impulse test

    - Equipment grounding and bonding test
    - Insulation resistance test
- Mechanical tests
    - Containment of moving parts
    - Leakage tests
    - Strength tests
- Environmental tests
    - Special environment installations
- Manufacturing and production tests
    - Dielectric voltage withstand test
    - Grounding and bonding system check
    - Maximum abnormal operating speed

However, specific tests and evaluation procedures for electrochemical energy storage systems are detailed in the UL 1973 standard.

3.1.5.3 IEC 61427-1 - Secondary cells and batteries for renewable energy storage — General requirements and methods of test - Part 1: Photovoltaic off-grid application

This component of the IEC 61427 standard covers the general requirements for secondary batteries used in photovoltaic energy systems and the methods of tests used to verify the performance of such batteries.

The test included in this standard are outlined in Table 14 below.

Table 14: IEC 61427-1 performance tests

Test	Test aim and evaluation
Capacity test	• This test aims to verify the rated capacity of the battery. • This is completed using currents specific to the battery type in question, alongside any relevant clauses in battery chemistry specific standards outlined in section 7.2 of this standard.
Generic cycling endurance test	• This test exposes batteries to generic cycling endurance according to the clauses (if any) in battery chemistry specific standards outlined in section 7.2 of this standard.
Charge retention test	• This test exposes batteries to charge retention tests according to the clauses (if any) in battery chemistry specific standards outlined in section 7.2 of this standard.

Cycling endurance test in photovoltaic applications (extreme conditions)	• This test exposes the battery to a number of photovoltaic specific endurance tests, designed to simulate service under extreme conditions.
	• Alongside a number of other conditions, this test consists of two phases:
	  ○ Phase A: shallow cycling at low state of charge
	  ○ Phase B: shallow cycling at high state of charge
	• A number of tests are then completed after cycling through both Phase A and Phase B.

3.1.5.4 IEC 61427-2 - Secondary cells and batteries for renewable energy storage — General requirements and methods of test - Part 2: On-grid applications

This component of the IEC 61427 standard covers the usage of secondary batteries for on-grid electrical energy storage applications. The required battery properties, endurance, and electrical performance, as well as the associated testing methods to review these characteristics are outlined. The test methods outlined are battery chemistry agnostic and can be applied to all types of secondary batteries.

This standard includes multiple general test conditions that must be adhered to. This includes:

- Defined accuracy of measurement equipment for:
  - Voltage measurements
  - Current measurements
  - Temperature measurements
  - Time measurements
- Test object considerations – the tested system shall include cells, modules or stacks. The battery management system and battery support systems will also be included if they are essential for the operation of the battery.
- Test object battery selection and size considerations. These can be defined as:
  - Full-sized battery
  - Test-object battery

The battery endurance tests included in this standard are outlined in Table 15 below. These endurance tests aim to determine the suitability of the battery to accept and deliver energy in a manner which is representative of the duty the battery will be required to perform when used in on-grid energy storage applications. The key stresses in this type of service include:

- Charge and discharge power levels per available energy content
- Operation when in a SoC less than 100%
- The high number of cycles the battery will accomplish during its service life

Table 15: IEC 61427-2 summery of battery endurance tests

Test	Test aim and evaluation
Test for endurance in frequency-regulation service	• Supply and accept continued constant power pulses aligning to frequency-regulation services. • Tolerate energy transfers multiple times per hour and during full 24-hour periods, without exceeding the manufacturer's specified operating voltage limits. • The specific cycling parameters are included in the standard document. • Figures detailing the frequency regulation service test routine profile are also provided.
Test for endurance in load-following service	• Supply and accept continued constant power pulses aligning to load-following services. • Tolerate energy transfers multiple times per hour and during full 24-hour periods, without exceeding the manufacturer's specified operating voltage limits. • The specific cycling parameters are included in the standard document. • Figures detailing the frequency regulation service test routine profile are also provided.

Test for endurance in peak-power shaving service	• Supply multiple constant power discharge pulses and tolerate such energy transfers without exceeding the manufacturer's specified operating voltage limits. • The specific cycling parameters are included in the standard document. • Figures detailing the frequency regulation service test routine profile are also provided.
Test for endurance in photovoltaic energy storage, time-shift service	• Accept daily photovoltaic energy at a range of constant power values. • Deliver the stored energy at defined power levels. • Tolerate the daily energy transfers without exceeding the manufacturer's specified operating voltage limits. • The specific cycling parameters are included in the standard document. • Figures detailing the frequency regulation service test routine profile are also provided.

3.1.5.5 IEC 62933-2-1 – Electrical energy storage (EES) systems Part 2-1: Unit parameters and testing methods – General specification

This section of the IEC 62933 standard outlines the unit parameters and testing methods for electrical energy storage systems. The specific energy storage devices and technologies are not included within the scope of this section. The electrical energy storage systems are classified in this document into multiple different categories, these are:

- Mechanical
- Electrochemical
- Chemical
- Electrical
- Thermal

As well as classifying the method of energy storage, the applications of the electrical energy storage systems are detailed. These applications are divided into three separate classes as follows:

- Class A applications
  - Frequency regulation
  - Fluctuation reduction
  - Voltage regulation
- Class B applications
  - Peak shaving and peak shifting
- Class C applications
  - Back-up power

An extensive overview of the testing unit parameters is included in this section of the IEC 62933 standard. This not only includes a list and description of all the required unit parameters, but also defines the standard testing conditions, environmental conditions for reference and an overview of the typical architecture of an electrical energy storage system. This section is followed by the specific testing methods and procedures that are to be employed, divided into 3 distinct categories:

- Parameter tests
- Performance tests
- System implementation tests

A summary of these three categories and the tests included within each of them is provided in Table 16, Table 17, and Table 18 below.

Table 16: IEC 62933-2 summary of the parameter tests

Test	Test aim and summary
Actual energy capacity test	• This aims to define the energy capacity of the electrical energy storage system under test. • The test includes full discharge and charge cycles.
Input and output power rating test	• The test aims to ascertain the constant rated power that can be input or output from the electrical energy storage system. • Active, reactive and apparent power tests are included in this section.
Roundtrip efficiency test	• This test determines the relative ratio between the amount of energy input to the electrical energy storage system during charging and the amount of energy output that the system can delivery when discharging.
Expected service life test	• The estimated service life is generated via this test by analysing the degradation characteristics due to ageing of the electrical energy storage system.
System response test, step response time and ramp rate	• The electrical energy storage system response time is determined via the testing procedure detailed in this section. • Diagrams depicting the step and ramp profiles are provided in this section.
Auxiliary power consumption test	• The power consumptions of auxiliary devices are measured at the point of connection for a range of operating conditions. • Additional scenarios for auxiliary subsystem connection are also detailed.
Self-discharge of ESS system test	• The specific procedure for the measurements of the electrical energy storage system self-discharge is outlined in this section.
Rated voltage and frequency range test	• The required procedure and tolerance range for the determination of the rated voltage and frequency range is defined in this section. • Four test cases are detailed.

Table 17: IEC 62933-2 summary of application class performance tests

Application type	Tests included
Class A applications	• Duty cycle roundtrip efficiency test • Fluctuation reduction test
Class B applications	• Duty cycle roundtrip efficiency test
Class C applications	• Black start output voltage

Table 18: IEC 62933-2 summary of system implementation tests

Test	Test aim and summary
Visual inspection	• This aims to ensure the installation of the required components of the electrical energy storage system, alongside the additional electrical equipment and power connections. • The specific items included in the inspection are detailed here.
Continuity and validity of conductors	• The verification of the continuity of conductors shall be completed via visual inspection, continuity test and insulation resistance tests in accordance with IEC 60364 or IEC 61936.

Earthing test	• This is designed to verify the suitability of the earthing arrangement, with a specific test checklist provided.
Insulation test	• Low voltage insulation resistance test according to IEC 60364-6. • IEC 61936 utilised for withstand voltage testing of electrical energy storage systems exceeding 1 kV AC or 1.5kV DC.
Protective and switching device test	• This is designed to verify the suitability of the protective and switching devices used. • The specific inspection and testing methods are outlined in this section.
Equipment and basic function test	• Specific tests are outlined in this section to verify the suitability and functionality of the electrical energy storage equipment. These include: ○ Starting and stopping test ○ Load tripping test ○ Operating cycle test ○ Measurement, control, and monitoring system test ○ Communication test
Grid connection compatibility test	• Specific tests are outlined in this section to verify the grid connection compatibility. These include: ○ Measurement of harmonic currents ○ Verification test to temporary voltage drop
Availability energy test	• The requirement of the electrical energy storage system to have a means or device to measure the available energy are defined. • The potential methods with which the available energy level can be tested are outlined.
EMC immunity test	• Immunity levels of the system within an EMC environment are to be demonstrated based on: ○ IEC 61000-6-1 ○ IEC 61000-6-2 ○ IEC 6100-6-3-5

4 Literature review of existing standards – chemistry specific

4.1.1 Chemistry-specific standards relevant to future RNZB standardisation

4.1.1.1 Standards specifying the chemistry specific safety considerations of cells and batteries for different use cases

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

This standard specifies both the requirements and tests to ensure the safe operation of lithium cells and batteries considered for industrial applications (including stationary applications). General safety considerations for lithium cells and batteries are included in this document, covering topics that include the insulation and wiring of these systems, venting, cell/module/battery pack assembly into battery systems, and the safe operating regions of lithium battery systems. Furthermore, general test type conditions are summarised prior to the specification of the battery tests and requirements.

The specific tests and battery requirements provided in this standard are separated into three distinct sections, charging procedures for test purposes, reasonably foreseeable misuse, and considerations for internal short-circuit. These sections are summarised in Table 19 below:

Table 19: IEC 62619 summary of the specific cell tests and requirements

Specific requirements and tests section	Section summary
Charging procedures for test purposes	• This section details how the test batteries are to be prepared for charging, and the specific requirements of the charging procedure. This includes ambient temperature limits and current values.

Reasonably foreseeable misuse	• Many misuse scenarios are defined and tested within this section. These scenarios and tests include:
	  ○ External short-circuit test on the cell or cell block
	  ○ Impact testing of the cell or cell block
	  ○ Drop testing of the cell, cell block or battery system
	  ○ Thermal abuse testing of the cell or cell block
	  ○ Overcharge testing of the cell or cell block
	  ○ Forced discharge testing of the cell or cell block
	• Figures depicting the specific testing procedure are provided for both the drop and impact testing of the cell or cell block.
	• Specific testing procedures, requirements and acceptance criteria are provided for all of the test defined in this section of the document.

Considerations for internal short-circuit	• This test aims to evaluate the design of the cell and ensure that a short-circuit within the cell will not result in a fire. This evaluation comprises of two distinct tests. • The first test involves a forced short-circuit within the cell under test, which should not result in a fire or explosion. • The second test evaluates the ability of the battery system to survive the thermal runaway of a single cell, without the fire propagating through the rest of the battery system. • The specific, detailed testing procedures are provided in both of these sections, including the definition of the acceptance criteria.

The functional safety of lithium battery systems is also reviewed in this standard. This involves assessing the control systems and softwares that ensure the safe operation of lithium battery systems. This requires a process hazard, risk assessment and mitigation of the battery system to be completed by the battery system manufacturer. The focus of this section is on the battery management system, with general requirements of this component provided. This component is typically required to ensure that a battery system is protected from operating outside of its safe operating area, monitoring the current state of the battery system, and balancing the cells within the system. The following requirements are detailed in this section of the standard:

- Overcharge control of voltage of the battery system
- Overcharge control of the current of the battery system
- Overheating control of the battery system.

Each of these sections have defined operating requirements and test procedures to evaluate the performance of the test battery system. Clear acceptance criteria are also provided to review the outcome of the testing procedure.

4.1.1.1.2 IEC 62485-5 Safety requirements for secondary batteries and battery installations Part 5: Safe operation of stationary lithium-ion batteries

This standard describes the safety requirements and required protective measures to provide protection from the hazards that are generated by electricity and chemical substances related with the use of secondary batteries. Measures are also provided to maintain the functional safety of such batteries and battery systems. The scope of this document covers one or more stationary batteries that have a maximum aggregate DC voltage of 1500V to any DC part of the power network. The requirements in this standard cover safety aspects associated with the installation, use, inspection, maintenance, and disposal of lithium-ion batteries that are used in stationary applications.

The main protection measures outlined in this document cover the hazards that are expected in either normal operation or under expected fault conditions. These hazards are typically generated from one of the following items:

- Electricity
- Short-circuits
- Electrolyte
- Gas emissions
- Fire
- Explosions

Protection against electric shock

Alongside referencing relevant safety provision standards such as IEC 62485-1, IEC 60364-4-41 and IEC 61140, this section provides an overview of the basic protection measures that should be employed against contact with live parts. Additional topics covered in this section of the document include:

- Fault protection measures - this includes not only general fault protection measures, but also specific protection measures by automatic disconnection of supply for a range of system topographies. Protection by electrical separation and insulation measures are also included.
- Protective measures related to extra-low voltage provided by safety extra-low voltage (SELV), protective extra-low voltage (PELV) and functional extra-low voltage (FELV) are specified.

Disconnection and separation

This section provides a list of devices (to be relevant to direct current and afford the necessary isolation) that are to be provided to disconnect the battery installation from all lines of incoming and outgoing circuits from earth potential.

Prevention of short-circuits and protection from other effects of electric current

This section highlights that as well as the hazards associated with electric shocks, other hazards can be generated via the flow of current within the battery system. This is especially prevalent during a fault condition, where very high currents may occur and the ability for the battery terminals to be switched off may be impaired. Typical design factors such as vented cells are often employed to release gas during such events, without creating the risk of cell or battery bursting. However, the ignition of such vented gases must be considered.

Specific requirements are outlined in this standard relating to several specific topics. These include short-circuit prevention and mitigation, instructions and protective measures for maintenance activities, and potential leakage current mitigations.

- Short-circuits – The main risks of battery short-circuit are outlined, including high heat generation due to high currents leading to molten metal production, sparks, explosions and vaporisation of electrolyte. Specific design requirements are outlined for the main connections at the battery terminals, as well as requirements for the overcurrent protective devices that are employed. All battery connections are required to be installed in such a way that short-circuit events should not be possible to occur under any foreseeable conditions. The following standards are references regarding the type of conductor arrangement of unprotected conductor sections:
    - IEC 60364-4-43
    - IEC 60364-5-53

  For the calculation and estimation of the battery short-circuit current, and the reasonably foreseeable misuse of external short-circuit of the battery, the following standards should be references:
    - IEC 61660-1
    - IEC 61660-2
    - IEC 62619
    - IEC 62133-2
- Maintenance instructions – The battery maintenance instructions shall include suitable work practises, as well as both protective procedures and protective equipment requirements that should be followed during maintenance.
    - Protective measures during maintenance – Battery system design requirements are outlined that are intended to minimise the risk of injury to personnel working close to the battery during maintenance. These design requirements include battery terminal covers to minimise exposure to live parts and fuse carriers which are intended to prevent potential contact with live parts. Maintenance procedures are also outlined in this section, with specific requirements for battery system where the maximum voltage is > 120V DC.
- Leakage currents – Lithium-ion batteries must be installed in line with the manufacturer's recommendations and should be kept clean and dry to avoid potential fire or corrosion related risks. Minimum isolation resistance figures are provided, as well as other specific requirements of the insulation regarding its ability to resist the adverse environmental effects of temperature, dampness, gases, steam and mechanical stress.

Provision against hazards

This section states the requirement for lithium-ion batteries to always be operated within the voltage, temperature and current operating limits that are specified by the cell manufacturer, in accordance with Annex A of IEC 62619:2017. Specific requirements are outlined for the following topics:

- Charging modes – Here the typical charging mode requirements for stationary batteries are outlined, with specific attention paid to operation at the low end of the operating temperature range of the battery. This provides details to adjust the charging currents in such operating temperature regions to avoid potential lithium plating on the battery anode material.
- Overcharging or over discharging under fault conditions – Here, conditions such as charger or load malfunction are stated as posing a risk to the battery, with potential adverse effects such as harmful gas production. It is required for electrical precautions against charger malfunction to be provided, such as by lowering the charge voltage below the open circuit upper limit charging voltage of the cells. Another key safety function is the disconnection of the battery, with this function required to be redundant or have a suitable safety integrity level.
- Prevention of electrostatic discharge when working with batteries – Specific recommendations regarding conditions which may cause the build-up of electrostatic charges are provided. IEC TR 61340-1 and IEC 61340-5-1 and specifically referenced.

Provision against hazards posed by chemical substances

If lithium-ion batteries are damaged, misused, or operated incorrectly, then dangerous chemical substances may be released. Manufacturer's safety instructions must be followed and should be provided in product-specific documentation. Manufacturer's instructions must specify the harmful chemical substances which can be released or occur by a reaction with the environment, which may take the form of a safety data sheet.

A list of initial actions that are to be followed in the event of a hazardous chemical release are outlined. These include specific instructions for the following events and contact points:

- Eye or skin contact
- Release of hazardous quantities of electrolyte
- Smoke or fire events
- Contact with the eyes or skin
- Swallowing
- Respiratory tract
- Burns

Accommodation, housing

This section of the document provides a list of the potential types of accommodation that can be used to house the battery energy storage system. Furthermore, the factors that should be considered when selecting the appropriate accommodation type are also detailed. The main reasons for selecting a battery enclosure are listed, and include the following:

- Protection against external hazards and those generated by the battery
- Protection from unauthorised personnel gaining access to the battery
- Protection against external environmental influences
- Protection against the propagation of fire

This section outlines the specific requirements that must be met for separate battery rooms to be used, as well as the specific requirements for the use of specially separated battery housing areas in rooms that accommodate electrical equipment. Specific design requirements are outlined that shall be applied when housing batteries within an enclosure. These design considerations include mechanical load bearing capabilities of mounting systems, ventilation performance, battery module distancing, prevention of access to hazards from unauthorised personnel, and adequate access provided for maintenance work. Escape path requirements and inspection, maintenance and charging space specifications are outlined, as well as the details regarding the recommended spacing design related to the use of equipment of specific dimensions within the accommodation.

Special note is made on the accommodation of lithium-ion batteries in combination with batteries that contain aqueous electrolyte (such as lead-acid and nickel-cadmium batteries) in the same space. The requirement to consider the specific risks associated in this scenario is highlighted, with risks such as corrosion of the lithium-ion batteries from acid spills being specified as an example.

Charge current requirements

The effects of ripple currents are highlighted, with heat generation within the cell being an identified risk that should be minimised. The equation for calculating the effect of the alternating component of the charge current is provided. Specific requirements regarding the maximum allowable ripple current are outlined, with manufacturer limits being

adhered to and peak voltages and currents (generated by ripple currents) required to remain below their maximum charge values.

Identification labels, warning notices and instructions for use, installation and maintenance
Labels related to warnings and notices within rooms containing battery systems are highlighted, with specific reference made to the IEC 60417 and ISO 3864 standards. Furthermore, specific identification labels or markings on cells, modules and battery packs or systems shall include all of the information required by IEC 62620.

Within the vicinity of the battery installation the following items shall be supplied and displayed:

- Name of the installer
- Date of commissioning
- Safety recommendations and installation, operation and maintenance instructions
- Information regarding the required disposal and recycling measures

Transportation, storage and environmental aspects
Lithium-ion batteries are regulated as dangerous goods by the United Nations Transport Organization (and other transport authorities). This section provides a list of all of the current UN directives and recommendations that apply to the transport of lithium-ion batteries via different transportation methods.

Inspection and monitoring
Inspection and monitoring items that are specific to lithium-ion batteries are provided in this section. The requirements for all inspection and maintenance to be carried out according to the recommendations from the manufacturer are also stated. IEC 62620:2014 includes references regarding the completion of capacity tests (if they are required).

Specific criteria that are to be included in the inspection process of the battery system are provided, as well as the resulting actions that are to be undertaken based on the result of the inspection.

Annexes

- Annex A – (informative) Charging methods and modes of operation
- Annex B (normative) Electromagnetic compatibility

4.1.1.1.3 IEC TR 61438 - Possible safety and health hazards in the use of alkaline secondary cells and batteries – Guide to equipment manufacturers and users - Edition 1.0 Secondary cells

This standard applies to nickel-cadmium cells and provides details regarding the reduction of risks to both persons and properties. This standard acts as a guide to both equipment manufacturers and application engineers, reporting the technical aspects of the possible hazards related to nickel-cadmium batteries. The information included in this standard should be incorporated into the application design and user instructions provided with the battery. In the case that single cells or batteries are sold directly by the manufacturer to the end-user, the manufacturer must ensure that this information is provided to the end-user.

This standard details the specific conditions which are necessary to create each of the hazards associated with nickel-cadmium cells and batteries. All possible hazards that are inherent in the particular application, use and possible abuse of nickel-cadmium batteries are to be identified and characterised in this document. The hazards that are included in the main content of this document include:

- Hydrogen explosion
- Pressure rupture
- Chemical burns due to exposure to the electrolyte
- High power levels resulting in shorting or fires
- High voltage levels resulting in the potential for electric shocks to occur
- Thermal runaway events
- Disposal

All of these identified hazards are presented with accompanying examples of misuse which may trigger such a hazard, as well as actions which may mitigate the particular hazard. These hazards are also considered from the perspective of both sealed and vented nickel-cadmium cells.

4.1.1.1.4 UL 1642 – UL standard for safety lithium batteries

The requirements in this standard apply to both primary and secondary lithium batteries that are to be used as power sources in products and are intended to be either technician or user-replaceable. The aim of this standard is to reduce the risk of fire or explosion when lithium-based batteries are utilised within a product, as well as reducing the risk of any resultant injuries to persons. These requirements are dependent on the mass of metallic lithium contained within the battery, with specific requirements outlined in this standard for varying lithium mass categories.

This standard provides the details for the required tests for UL 1642 Certification. These tests include:

- Short-circuit tests
- Abnormal charging test
- Crush test
- Impact test
- Shock test
- Vibration test
- Heating test
- Temperature cycling test
- Low pressure test for altitude simulation
- Project test

For each of these tests the test methodology and test conditions are clearly defined, alongside the specific test acceptance criteria.

Furthermore, this standard provides details regarding the marking requirements that shall be met by the battery manufacturer. These include legibly and lastingly marking the lithium batteries with details such as the name, trade name, and other descriptive of the manufacturer by which the organisation responsible for the manufacturer of the product can be identified. The product should also have a distinctive part number (or equivalent) marked, alongside a date code or other dating period of manufacture that does not exceed three consecutive months. If the manufacturer produces a battery at more than one factory, then each of the battery-packaging shall have a characteristic to mark the product as being produced in a particular factory or facility.

4.1.1.1.5 Additional technology or application specific standards for reference

- UL 2054 – UL Standard for Household and Commercial Batteries
- UL 1989 – UL Standard for Safety Standby Batteries
- UL 1778 – UL Standard for Safety Uninterruptable Power Systems
- BSI 20/30422454 DC - Draft BS EN IEC 62282-6-101 Fuel cell technologies. Part 6-101: Micro fuel cell power systems – Safety – General requirements (in development)

4.1.1.2 Standards specifying the marking, tests and requirements for secondary cells and batteries

Multiple existing standards provide the specific requirements for the marking, designation, dimensions, tests, and other requirements for different battery chemistries (and specific cell types within these chemistries, such as vented and sealed variants). These standards share much of the same scope, but contain differences catered to the specific battery chemistry associated with them. A similar, Nickel Zinc chemistry specific standard will need to be generated for Nickel Zinc batteries.

The following standards provide examples related to multiple specific battery chemistries (and some specific cell construction types), with the main content types summarised for reference.

For many of these standards, where IEC standards specifying test conditions and requirements in special applications conflict with these general standards, the former takes precedence.

4.1.1.2.1 IEC 60622 - Secondary cells and batteries containing alkaline or other non-acid electrolytes Sealed nickel-cadmium prismatic rechargeable single cells

This standard provides the specific requirements for the marking, designation, dimensions, tests, and other requirements for sealed nickel-cadmium prismatic secondary single cells.

Mandatory cell designation markings, specific to sealed nickel-cadmium prismatic secondary single cells are provided, with the required cell designation dependent on the discharge characteristics of the cell in question. Additionally, optional cell designations are also detailed in this standard, alongside the cell marking requirements. The allowable dimensions of these cells are included in this standard, with the acceptable width, height, and length dimensions all being specified for each potential container type.

Alongside these requirements, this standard also includes the required electrical tests particular to these cells. These tests include:

- Charging procedure for test purposes
- Discharge performance at several temperatures
- Charge retention
- Endurance
- Charge acceptance at constant voltage
- Overcharge
- Safety device operation
- Gas leakage test
- Storage

For each of these tests the test methodology and test conditions are clearly defined, alongside the specific test acceptance criteria.

The design requirement of the mechanical tests is to be based on the intended application of the cells in question. The standards outlined in the technology-agnostic section of this literature review will provide example mechanical tests that are related to specific battery use cases.

Further requirements regarding the physical appearance of the cells are also provided in this standard. The cells are required to undergo a visual inspection to ensure that there are no signs of damage. Any deformation of the cells must be within the tolerances that are outlined in the drawings provided by the cell manufacturer.

To show compliance with the requirements in this standard, specific approval and acceptance criteria are to be adhered to. Two main conditions are required to be met, 'type approval' and 'batch acceptance.

- Type approval – the number and grouping of tested cells is described, as well as the applicable tests that are to be applied to each group of test cells. The acceptable number of defective cells in each testing group is also provided. All this information is summarised in a 'Sequence of test for type approval' table provided in the standard document.
- Batch acceptance – the tests in this section are applicable to deliveries of individual cells. The sampling procedure should adhere to IEC 60410. A table is provided in the document for the recommended test sequence for batch acceptance.

4.1.1.2.2 IEC 60623 - Secondary cells and batteries containing alkaline or other non-acid electrolytes - Vented nickel-cadmium prismatic rechargeable single cells

This standard provides the specific requirements for the marking, designation, dimensions, tests, and other requirements for vented nickel-cadmium prismatic secondary single cells.

Mandatory cell designation markings, specific to vented nickel-cadmium prismatic secondary single cells are provided, with the required cell designation dependent on the discharge characteristics of the cell in question. Additionally, optional cell designations are also detailed in this standard, alongside the cell marking requirements. The allowable dimensions of these cells are included in this standard, with the acceptable width, height, and length dimensions all being specified for each potential container type.

Alongside these requirements, this standard also includes the required electrical tests particular to these cells. These tests include:

- The charging procedure for test purposes, including both the charging procedure on constant current and the charging procedure based on constant voltage at a given current.
- The discharge performance requirements at different temperatures and at a high rate of current
- Charge retention tests
- Endurance cycling tests
- Charge acceptance tests at constant voltage
- Vent plug operation
- Electrolyte retention tests
- Storage period tests

For each of these tests the test methodology and test conditions are clearly defined, alongside the specific test acceptance criteria.

The design requirement of the mechanical tests is to be based on the intended application of the cells in question. The standards outlined in the technology-agnostic section of this literature review will provide example mechanical tests that are related to specific battery use cases.

Further requirements regarding the physical appearance of the cells are also provided in this standard. The cells are required to undergo a visual inspection to ensure that there are no signs of damage. Any deformation of the cells must be within the tolerances that are outlined in the drawings provided by the cell manufacturer.

To show compliance with the requirements in this standard, specific approval and acceptance criteria are to be adhered to. Two main conditions are required to be met, 'type approval' and 'batch acceptance.

- Type approval – the number and grouping of tested cells are described, as well as the applicable tests that are to be applied to each group of test cells. The acceptable number of defective cells in each testing group is also provided. All this information is summarised in a 'Sequence of test for type approval' table provided in the standard document.
- Batch acceptance – the tests in this section are applicable to deliveries of individual cells. The sampling procedure should adhere to IEC 60410. A table is provided in the document for the recommended test sequence for batch acceptance.

4.1.1.2.3 IEC 60896-11 - Stationary lead-acid batteries Part 11: Vented types General requirements and methods of tests

This section of the IEC 60896 standard applies to lead-acid batteries and cells which are to be used in stationary applications. Its purpose is to define the general requirements and main characteristics of cells of this chemistry and use case. Furthermore, the test methods required to validify these requirements and characteristics are provided.

The battery and cell requirements include:

- Mechanical strength
- Electrolyte levels and reserve
- Capacity
- Endurance
- Charge retention
- Short-circuit current and internal resistance

The required cell and battery tests (and other testing related content) include:

- Accuracy of measuring equipment
- The required preparation of cells and batteries for testing
- Capacity test
- Endurance testing
- Charge retention testing
- The determination of the short-circuit current and internal resistance

Further information included in this document outlines the cell and battery marking requirements. Items such as the voltage, manufacturer or suppliers type reference, capacity, date of manufacture, manufacturer's or supplier's name and the electrolyte density are required to be permanently marked on the cell or monobloc. The marking of the cell polarity is also required, in accordance with IEC 60417.

4.1.1.2.4 IEC 62620 - Secondary cells and batteries containing alkaline or other non-acid electrolytes — Secondary lithium cells and batteries for use in industrial applications

This standard provides the specific requirements for the marking, designation, dimensions, tests, and other requirements for lithium secondary cells and batteries for uses that include stationary applications. Since this covers various industrial applications, it includes requirements which are common to many different applications.

The various marking requirements for lithium cells and batteries are provided in this document. These are indicated on either the cell, battery system or the instruction manual. The information required to be marked includes the rechargeable (or non-rechargeable) nature of the cell, the polarity, the date of manufacture, the rated capacity, the nominal voltage, and the watt-hour value. Other information is also specified, and the required or voluntary nature of each marking is provided, alongside the specific marking location requirement.

Electrical test specific to secondary lithium cells are included in this document. The tests include:

- The charging procedure for test purposes
- The discharge performance under a range of specific conditions
- The charge retention and recovery
- The cell and battery internal resistance
- Endurance

For each of these tests the test methodology and test conditions are clearly defined, alongside the specific test acceptance criteria.

The type test conditions and protocols are to be agreed between the manufacturer and the customer. However, test type conditions are provided in this standard for when this is not the case. This section includes items such as the sample size, ambient test temperature and cell, cell block or battery dimensions and tolerances.

4.1.1.2.5 IEC 61951 - Secondary cells and batteries containing alkaline or other non-acid electrolytes

This standard details the requirements for the marking, designation, dimensions, tests, and other requirements for cells and batteries for use in any orientation, for portable applications. This standard contains two sections that are each relevant to specific cell and battery chemistries. These sections are outlined below:

- IEC 61951-1 – for secondary sealed nickel-cadmium small prismatic, cylindrical and button cells and batteries
- IEC 61951-2 - for secondary sealed nickel-metal hydride small prismatic, cylindrical and button cells and batteries

These sections of the IEC 61591 standard contain much of the same scope, with the specific information based on the different requirements of the two cell chemistries.

The cell and battery designation and marking section of these documents include details for the designation of the different battery types considered:

- Small prismatic cells and cylindrical cells
- Button cells
- Batteries

Designation letters are utilised to specify the rated discharge of the different types of cells, and other characteristics such as permanent charge at elevated temperatures and rapid charging are also designated, among others. Minimum marking information requirements are also outlined for each of the cell types, including aspects such as:

- Rated capacity

- Nominal voltage
- Polarity
- Date of manufacture
- Name or identification of the manufacturer or supplier

The allowable dimensions of these cells are included in this standard, with the acceptable width, height, and length dimensions all being specified for each potential container type. Alongside these requirements, this standard also includes the required electrical tests particular to these cells. These tests include:

- The charging procedure for test purposes, specified for both the cell and battery level
- The discharge performance under different conditions
- The charge retention
- Endurance
- Charge acceptance at constant voltage
- Overcharge for multiple different cell classifications
- Safety device operation
- Storage

The IEC 61591-1 document also includes the following electrical tests:

- Charge acceptance at +55°C (for certain cell types)
- Trickle charge acceptance for (for certain cell types)
- Internal resistance

For each of these tests the test methodology and test conditions are clearly defined, alongside the specific test acceptance criteria.

The mechanical tests and safety requirements are provided in IEC 61959 and IEC 62133-1 respectively. Both of these standards are specific to secondary cells, and the batteries made from them, that are intended for use in portable applications. The mechanical tests in IEC 61959 include vibration and free fall tests, whilst the safety requirements in IEC 62133-1 cover general safety aspects and the specific requirements and tests for the charging procedure, intended usage and reasonably foreseeable misuse.

The type test conditions and protocol are to be agreed between the manufacturer and the customer. However, test type conditions are provided in this standard for when this is not the case. This section includes items such as the sample size, ambient test temperature and cell, cell block or battery dimensions and tolerances.

4.1.1.2.6 IEC 63056 - Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries for use in electrical energy storage systems

This standard comes under the umbrella of the standard IEC 62619. This standard covers the relevant safety standards applicable for secondary lithium cells and batteries that are to be used in electrical energy storage systems. The IEC 63056 document specifies both requirements and tests regarding the safety of lithium cells and batteries (which have a maximum nominal DC voltage of 1500V). Whilst general safety requirements for secondary lithium cells and batteries for use in industrial applications can be found in IEC 62619, this document adds additional detail and specific requirements for electrical energy storage systems. The applications which are included within the scope of the IEC 63056 document include, but is not limited to:

- Telecommunications

- Photovoltaic systems
- Large on-grid and off-grid energy storage
- Stationary engine starting
- Cells and batteries for uninterruptable power supplies

Figure 2 within this document also provides a visual representation of the content that is covered in the scope of IEC 63056.

The specific requirements and tests for lithium batters for EES applications are summarised below:

- Basic requirements
- Resistance to abnormal heat
- Casing material for battery system that can be transported for installation or maintenance
- Electric insulation check during transport and installation
- Charging procedures for test purposes
- Protection against short circuit during transport and installation
- Protection for reverse connection
- Over discharge control of battery system voltage
- Drop tests

Alongside the specific requirements and tests, a number of marking and designation requirements are detailed in this document.
Portable systems (500Wh and below) are covered in IEC 61960-3.

4.1.1.3 Standards providing the recommended practise for maintenance, testing and replacement of specific vented battery types for stationary applications

Multiple standards exist to provide the specific requirements for the Maintenance, Testing and Replacement of different battery chemistries (and specific cell types within these chemistries, such as vented and sealed variants) used in stationary applications. These standards share much of the same scope, but contain differences catered to the specific battery chemistry associated with them, and the intended service provided by the stationary battery system. A similar Nickel Zinc chemistry specific standard will need to be generated for vented Nickel Zinc batteries.

The following standards provide examples related to multiple specific battery chemistries (and some specific cell construction types), with the main content types summarised for reference.

Maintenance, testing and replacement:

- IEEE 1106 - IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-cadmium Batteries for Stationary Applications (Recommendation)
- IEEE 1657 - IEEE Recommended Practice for Personnel Qualifications for Installation and Maintenance of Stationary Batteries (Recommendation)
- IEEE 450 - IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead Acid Batteries for Stationary Applications (Recommendation)
- IEEE 1188 - IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead Acid Batteries for Stationary Applications (Recommendation)

4.1.1.3.1 IEEE 1106 - IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-cadmium Batteries for Stationary Applications (Recommendation)

This standard provides recommendations for vented nickel-cadmium batteries used for standby operation in stationary applications. These recommendations include the installation design and procedures, as well as maintenance recommendations and testing procedures for vented nickel-cadmium batteries. Separate recommendations are provided for use in renewable energy systems, such as wind turbines and photovoltaic systems. It is worth noting that the sizing, battery qualification and any other battery types (including sealed nickel-cadmium) are outside the scope of this standard.

The main purpose of this document is to provide recommended procedures that can be implemented to optimise the lifetime and performance characteristics of nickel-cadmium batteries used in this specific use case.

The main content of this standard is summarised below.

Safety aspects

General safety aspects regarding protective measures for the personnel working in proximity to the battery system are included. These safety criteria are specific to the cell chemistry and type, as well as their use for stationary standby operation. Details regarding the required protective equipment and tools are provided, as well as the identification of the potential hazards associated with stationary battery systems. Furthermore, the methods and precautions that should be employed during maintenance, testing and replacement of batteries are outlined, alongside the requirement for only qualified personnel to perform work on such battery systems.

Installation design criteria

The design criteria specified in this standard include the location and mounting of the batteries within the battery system. Furthermore, hazard mitigation design requirements such as consideration of seismic impacts and the system ventilation requirements are detailed. Finally, recommendations regarding the specific instrumentation and alarms are outlined in this section.

Installation procedures

The main stages associated with the installation of vented nickel-cadmium cells are defined in this section of the document. The relevant procedures for each of these stages are detailed. These main stages are defined as:

- Receiving and storage of the batteries prior to assembly
- Assembly of the battery system
- Initial charging of the battery system

Maintenance

General maintenance procedures are outlined in this section of the document. A list of the recommended inspections and their corresponding criteria are also included. Alongside these, the recommended corrective actions based on the outcome of the inspection process are provided.

Test schedule

A recommended test schedule for vented nickel-cadmium batteries is provided. This schedule includes details regarding the main acceptance criteria of these tests, as well as the expected performance characteristics of the battery system

The battery test procedure

For each of the battery tests, the recommended procedure is provided in this section of the document. Items such as the initial test conditions, the test length and relevant discharge rate are provided for each test. Specific methods and procedures are outlined for the recommended capacity tests of the battery system, as well as additional service tests and restoration recommendations.

Additional recommendations

A range of other recommendations are included in this standard. These include the specific criteria that are recommended for use in determining whether the replacement of cells or batteries is required. Furthermore, specific information regarding the reapplication and recycling of vented nickel-cadmium cells that have been used in stationary standby applications are provided. The annexes included in this standard also provide a range of informative information relevant to vented nickel-cadmium batteries. These annexes include:

- Information regarding nickel-cadmium battery construction, electrolyte, charging voltages and operational temperature.
- Relevant state of charge determination and charging recommendations
- Corrective actions for a range of situations
- Prolonged float charging effects of nickel-cadmium battery capacity
- Typical nickel-cadmium ageing and end-of-life criteria
- A comparison of different testing methods, such as time and rate-adjusted performance test methods
- Reference to the relevant IEC 60623 standard for vented nickel-cadmium batteries for the general marking, designation, dimensions, tests, and other requirements.
- Internal ohmic measurements
- Details regarding the operation of vented nickel-cadmium batteries with renewable energy systems, including the required design, installation, maintenance and testing considerations.

4.1.1.3.2 IEEE 450 - IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead Acid Batteries for Stationary Applications (Recommendation)

The purpose of this standard is to provide the user with both information and recommendations regarding the maintenance, testing and replacement of vented lead-caid batteries that are used in stationary applications. This document contains recommendations to optimise the lifespan and performance of permanently installed vented lead-acid batteries that are to be used in standby service. This content includes maintenance recommendation test schedules and the relevant testing procedures to achieve this aim.
The main content included in this document is summarised below.

Safety

The main protective equipment that is recommended for use in lead-acid battery installations is provided. Furthermore, the required precautions and suitable maintenance and installation methods regarding to safety are outlined.

Maintenance

The recommended inspections and corresponding corrective actions are provided in this section, as well as general information relevant to the maintenance process.

Test schedule
Recommendations for both the performance and acceptance of relevant battery system tests are included in this section of the document. Modified performance tests are also detailed for reference.

Battery test procedure
For each of the battery tests, the recommended procedure is provided in this section of the document. Items such as the initial test conditions, the test length and relevant discharge rate are provided for each test. Specific methods and procedures are outlined for the recommended capacity tests of the battery system, as well as additional service tests and restoration recommendations.

Additional recommendations
Further recommendations are provided for the replacement of vented lead-acid batteries in standby stationary applications. Details regarding the recommended recycling practices for lead-acid batteries are also included, as well as the recommended methods for dealing with spill containment and management. The annexes included in this standard also provide a range of information relevant to vented lead-acid batteries. These annexes include relevant information regarding:

- State of charge
- Specific gravity
- Float voltage
- The urgency of corrective actions
- Visual inspection of batteries and installations
- Connection resistance measurements
- Alternative applications
- Effects of elevated electrolyte temperature on vented lead-acid batteries
- Modified performance testing methods and examples of these tests
- Alternative methods of completing inspections
- How to calculate battery's capacity
- Temperature-correction factors

4.1.1.3.3 IEEE 1188 - IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications

This standard provides the recommended practice for the maintenance, test scheduling, and testing procedures that can be used to optimise the lifespan and performance of valve-regulated lead-acid batteries that are for use in stationary applications. This standard also provides guidance regarding the proper replacement timing of batteries of this type and usage. Whilst the maintenance and testing programs that are defined in this standard focus on the technical issues regarding these activities, it is recommended that any user of this standard also considers aspects such as economics, equipment availability and personnel availability to develop a comprehensive maintenance and testing program.

The scope of this document does not cover stationary cycling applications, or any other components of the DC system.

The main content of this standard is summarised below.

Safety aspects
General safety aspects regarding protective measures for the personnel working in proximity to the battery system are included. These safety criteria are specific to the cell chemistry and type, as well as their use for stationary standby operation. Details regarding the required protective equipment and tools are provided, as well as the identification of the potential hazards associated with stationary battery systems. Furthermore, the methods and precautions that should be employed during maintenance, testing and replacement of batteries are outlined, alongside the requirement for only qualified personnel to perform work on such battery systems.

Maintenance
General maintenance procedures are outlined in this section of the document. A list of the recommended inspections and their corresponding criteria are also included. Alongside these, the recommended corrective actions based on the outcome of the inspection process are provided.

Test schedule
A recommended test schedule for vented nickel-cadmium batteries is provided. This schedule includes details regarding the main acceptance criteria of these tests, as well as the expected performance characteristics of the battery system

The battery test procedure
For each of the battery tests, the recommended procedure is provided in this section of the document. Items such as the initial test conditions, the test length and relevant discharge rate are provided for each test. Specific methods and procedures are outlined for the recommended capacity tests of the battery system, as well as additional service tests and restoration recommendations.

Additional recommendations
Further recommendations are provided for the replacement of valve-regulated lead-acid batteries in standby stationary applications. These include the criteria related to the replacement of batteries within this system, as well as the recommended records to be kept. The annexes included in this standard also provide a range of information relevant to vented lead-acid batteries. These annexes include relevant information regarding:

- How to determine the state of charge
- Voltage information
- Connection detail resistance measurements
- Calculation of the battery's capacity
- Temperature connection factors

4.1.1.3.4 IEEE 1657 - IEEE Recommended Practice for Personnel Qualifications for Installation and Maintenance of Stationary Batteries (Recommendation)

This standard aims to provide and outline the main items that should be covered by training programs for stationary battery installation and maintenance personnel. This document is structured as a syllabus for the benefit of both course developers and instructors delivering the content. This standard outlines the minimum skills requirements that are recommended for a battery technician working with stationary battery installations and does not limit the instructor of content developer from creating a more comprehensive curriculum.

This standard primarily applies to lead-acid and nickel-cadmium batteries used in stationary standby applications. The recommended practices for the installers and maintainers of the battery aim to ensure the personnel safety of these parties, as well as the safety and reliability of the battery and related systems. It is noted that some of the

information covered in this standard may be relatable to small off-grid cycling applications. However, there is limited information related to large energy storage cycling applications.

The main content of this document is summarised below.

Skill levels
The recommended skills levels and knowledge required of both technicians and instructors is outlined in this section of the document. Furthermore, the accreditations details for both of these roles are included.

Safety
A wide range of safety aspects are outlined for the perspective of battery installation and maintenance personnel competing their respective tasks on the battery system. These safety topics include:

- Work environment
- Personal protective equipment
- Electrical shock hazards
- Insulation
- Ladder safety
- Lockout/tagout
- Electrostatic discharge precautions
- Ventilation
- Working clearances, egress paths and task lighting
- Battery weight concerns
- Battery fire safety concerns
- Safety signs
- First aid
- Spill containment and clean-up

Basic DC theory and battery basics
The recommendation for relevant personnel to have a sufficient level of battery DC knowledge is outlined in this section. A range of content subjects are specified, these include:

- Relevant terminology
- Basic electrical components
- Basic mathematics
- Basics of electrical circuits
- Basics of rectification
- Basics of inverters
- Disconnects and overcurrent protection
- Grounded and ungrounded systems

Alongside the DC theory recommendations, this document provides content topics recommended to provide relevant personnel with a sufficient level of battery knowledge. The recommended battery topics include:

- General battery information
- Stationary battery types
- Basic constructions
- Failure modes and causes
- Charge and discharge characteristics

- Voltage and specific gravity

Documentation

Training content regarding the assessment of a range of documentation is recommended. The types of documents highlighted for inclusion in this training include:

- Applicable codes and standards to the battery installation
- Manufacturer documentation
- Reading of electrical and mechanical drawings
- Keeping records
- Job-specific documentation

Additional skills and information

Further skills recommended to be included are:

- Skills specific to the maintenance and installation of battery systems
- Cable management kills

It is also recommended that specific details regarding the recycling of lead-acid and nickel-cadmium batteries are included in the content.

4.1.2 Additional technology-specific standards for potential reference

4.1.2.1 Performance requirements

- IEC 62932-2-1 - Flow battery energy systems for stationary applications. Performance general requirements and test methods

4.1.2.2 Battery testing

- IEC 61056-1 - General purpose lead-acid batteries (valve-regulated types) - Part 1: General requirements, functional characteristics - Methods of test
- IEC 62932-2-1 - Flow battery energy systems for stationary applications. Performance general requirements and test methods

5 Standardisation roadmap

5.1.1 Standards to comply with to access main markets

5.1.1.1 Safety standards to comply with to access main markets

The standards detailed in section 3.1.2 of this document highlight the safety requirements and mitigating measures that must be implemented to facilitate access to multiple specific applications. These safety aspects include items that apply at a cell level, as well as requirements that are applicable all the way up to the installation level. Safety measures that protect personnel working in close proximity to electrical energy storage systems are also detailed in a number of these standards.

The specific markets and applications accessed via compliance with these standards include:

- Stationary batteries
- Grid-integrated ESS systems

These standards not only assess electrical hazards, such as potential exposure to electric shocks, component short circuits, and insulation from live parts, but also consider hazards specific to electrochemical energy storage technologies. Furthermore, hazards arising from auxiliary systems are also reviewed.

The following standards have been detailed in section 3.1.2 of this document:

- IEC 62485-1 - Safety requirements for secondary batteries and battery installations - Part 1: General safety information
- IEC 62485-2 - Safety requirements for secondary batteries and battery installations. Stationary batteries
- NFPA 855 - Standard for the Installation of Stationary Energy Storage Systems
- UL 9540A - ANSI/CAN/UL Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
- IEC 62933-5-1 - Electrical energy storage (EES) systems - Part 5-1: Safety considerations for grid-integrated EES systems - General specification
- IEC 62933-5-2 - Electrical energy storage (EES) systems - Part 5-2: Safety requirements for grid-integrated EES systems - Electrochemical-based systems
- UL 2436 - Outline of Investigation for Spill Containment for Stationary Acid and Alkaline Electrolyte Battery Systems

These standards provide technical design and performance requirements that must be adhered to in order to access these markets.

Additional safety standards exist for uninterruptible power systems, standby batteries, and household & commercial batteries. The main safety standards relating to these markets are outlined in section 3.1.2.8 and listed below:

- UL 2054 – UL Standard for Household and Commercial Batteries
- UL 1989 – UL Standard for Safety Standby Batteries
- UL 1778 – UL Standard for Safety Uninterruptable Power Systems

5.1.1.2 Standards outlining performance requirements to comply with to access main markets

The performance requirements of cells, batteries and electrical energy storage systems are outlined in multiple standards, which provide the relevant requirements for main battery use cases and markets. Furthermore, these standards can also include methods for validifying these component and system level performance levels. The requirements in these standards can include both electrical and mechanical performance, specific to the intended use case outlined in each standard document.

The specific markets and applications accessed via compliance with these standards include:

- On-grid applications
- Photovoltaic off-grid applications

The following standards have been identified and detailed in section 3.1.3 of this document:

- IEC 61427-2:2015 - Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications
- IEC 61427-1 - Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application
- IEC 62933-3-1 - Electrical energy storage (EES) systems Part 3-1: Planning and performance assessment of electrical energy storage systems - General specification.

5.1.1.3 Recycling legislation to comply with to access main markets

Two key documents regarding the recycling legislation and standards required to access main markets are detailed in section 3.1.4 and listed below. However, further analysis of relevant recycling legislation and directives is provided in Deliverable 2.3 of this Work Package.

- DIRECTIVE 2006/66/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL
- IEC 61429 - Marking of secondary cells and batteries with the international recycling symbol ISO 7000-1135

5.1.1.4 Testing standards to comply with to access main markets

Alongside technology specific standards that outline the general tests that cells must complete to verify their performance characteristics, specific standards exist that apply to cells and batteries intended for defined use cases and applications. Such standards are not necessarily limited in scope to only electrochemical energy storage methods, and often contain the relevant testing information for other energy storage technologies as well.

The specific markets and applications accessed via compliance with these standards include:

- Stationary applications (as well as applications in vehicle auxiliary power and light electric rail)
- Photovoltaic off-grid applications
- On-grid applications
- Uninterruptable power supply systems

The following standards have been detailed in section 3.1.5 of this document and provide details regarding the testing procedures and acceptance criteria required to facilitate the use of energy storage technologies within key markets and applications.

- UL 1973 - ANSI/CAN/UL Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications
- UL 9540 - Energy Storage Systems and Equipment
- IEC 61427-1 - Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application
- IEC 61427-2:2015 - Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications
- IEC 62933-2-1 – Electrical energy storage (EES) systems Part 2-1: Unit parameters and testing methods – General specification
- IEEE 1184 - IEEE Guide for Batteries for Uninterruptible Power Supply Systems

5.1.2 Recommendations for future standardisation

This section of the document highlights standardisation topics that are likely to be relevant for the future standardisation activities related to the RNZB technology. These recommended topics have been based upon existing standards that apply to other specific battery chemistries and cover a wide range of standardisation topics and requirements.

5.1.2.1 Standard that specifies any technology-specific safety considerations for RNZB cells and batteries and their use in battery systems or installations

General battery safety information for secondary batteries and battery installations is provided in IEC 62485-1 and IEC 62485-2, as well as other standards that are outlined in section 3.1.2 of this document. The IEC 62485-1 and IEC 62485-2 standards provide requirements and definitions for lead-acid, nickel-cadmium, and nickel metal-hydride batteries. The requirements can also be applied accordingly for other battery systems with aqueous electrolyte.

However, in line with the example standards outlined in section 4.1.1.1, RNZB batteries may require the generation of a standard that details any safety specific considerations for secondary RNZB batteries. Such a standard should provide technical information regarding the potential hazards associated with the use of RNZB cells and battery systems. Reference should also be made to the specific conditions that are necessary to create hazards, as well as the actions and procedures that can be implemented to mitigate these hazards.

Both the scope and main applications of this standard should be provided as an introduction to this document, alongside the relevant normative references. Furthermore, a section should be included to define all the general definitions used within the main text of this standard document.

Examples of this type of technology-specific standard include those outlined in Section 4.1.1.1.1 of this document.

There are a wide range of safety related topics that may require information or requirements that are specific to either the RNZB technology in general, or to the use of RNZB cells and batteries for certain applications. These potential topics are outlined below.

Outline of the hazards associated with the use of RNZB batteries

Any possible hazards that are inherent in the particular application, use and also possible abuse of RNZB batteries should be identified and characterised. Furthermore, the conditions which are necessary to create the identified hazards should be outlined, alongside the relevant mitigation measures that shall be employed. Typically, the hazards should be initially considered in a general manner before specific conditions for both vented and sealed cells (if applicable) are considered. The following list provides a number of hazards which may apply to the RNZB technology and are based on the requirements outlined in IEC TR 61438 related to alkaline secondary cells (which is discussed in section 4.1.1.1.3 of this document).

- Hydrogen explosion
- Pressure rupture
- Chemical burns due to exposure to the electrolyte
- High power levels resulting in shorting or fires
- High voltage levels resulting in the potential for electric shocks to occur
- Thermal runaway events
- Disposal

Protection against electric shock

Any specific electric shock considerations for the RNZB technology that are not covered in general safety standards should be outlined. This may include specific fault protection information regarding protection by automatic disconnection of supply, the use of class II equipment or equivalent insulation, and electrical separation. If protective measures via extra-low voltage provided by SELC, PELV and FELV are relevant then that may also be included.

Prevention of short-circuits and protection from any other effects of electric current

Specific requirements for the RNZB technology may be outlined in this section relating to short-circuit prevention and mitigation, instructions and protective measures for maintenance activities, and potential leakage current mitigations.

Provision against hazards

Hazards related to the charging modes of the RNZB battery, as well as the potential for overcharging and over discharging during fault conditions should be considered. Reference to the requirement to operate RNZB cells and batteries within specified voltage, temperature and current operating limits may also be included (this may also be in the form of a requirement to adhere to manufacturer's recommendation on these topics).

Provisions against hazards posed by chemical substances

Details regarding the potential for dangerous chemical substances to be released by RNZB cells and batteries if they are damaged, misused or operated incorrectly shall be out lined in this section. Manufacturers are required to provide product-specific safety instructions and documentation. This documentation must outline any harmful chemical substances which may be released or occur via a reaction with elements of the environment. Furthermore, a list of initial actions to be followed in the event of a hazardous chemical release are to be provided, including specific instructions regarding contact with the following points:

- Contact with the eyes or skin
- Swallowing
- Respiratory tract

Furthermore, specific instructions should also be provided for use in the following events:

- Release of hazardous quantities of electrolyte
- Smoke or fire events
- Burns

Accommodation and housing

The potential types of accommodation that may be used to house an RNZB battery energy storage system should be outlined, as well as the factors to consider when selecting an accommodation type. Any special notes regarding the housing of RNZB batteries alongside other specific battery types should be provided in this section.

Charge current requirements

Any specific requirements regarding the maximum allowable ripple currents in RNZB cells and battery systems are outlined, with manufacturer limits being adhered to and peak voltages and currents (generated by ripple currents) required to remain below their maximum charge values. The equation(s) required to calculate ripple currents are also to be provided if required.

Transportation, storage and environmental aspects

If RNZB cells and batteries are regulated as dangerous goods by the United Nations Transport Organization (and other transport authorities) then this section shall provide a list of all of the current UN directives and recommendations that apply to the transport of RNZB cells and batteries via different transportation methods.

Inspection and monitoring

Any RNZB battery system specific criteria that are relevant to inspection process of the battery system are to be provided, as well as the resulting actions that are to be undertaken based on the result of the inspection.

5.1.2.2 Standard that specifies the marking, tests, and requirements for secondary RNZB batteries.

In line with the example standards outlined in section 4.1.1.2, RNZB batteries will require the generation of a standard that specifies the general marking, tests, and requirements for secondary RNZB batteries. This standard will be utilised for all applications of these cells that do not fall under existing IEC standards for special applications. In such cases where there is an existing IEC standard that specifies test conditions and requirements for cells used in special applications, and there is a conflict with this generic 'marking, tests, and requirements standard', the former shall take precedence. Furthermore, if RNZB batteries of significantly different structure (for example the variance seen in sealed vs vented nickel-cadmium batteries), then additional versions of this standard may be required to cover these different battery characteristics.

A range of RNZB battery specific content will be required in this marking, tests, and requirements standard.

Examples of this type of standard include those outlined in section 4.1.1.2 of this document.

Scope

The scope will be required to provide an overview of the content of this standard and define the specific RNZB secondary cells that are covered by the standard. Furthermore, reference shall be made to any existing IEC standards which specify tests and requirements that take precedence over this standard document.

Normative references

References will need to be made to any existing standards that have some or all of their content constitutes requirements of this document. Examples of such standards include IEC 60050-482:2004 and IEC 60417.

Terms and definitions

For the purposes of this standard document, any terms and definitions used will need to be defined in this section, or included via a reference to another standard document, such as IEC 60050-482 (International electrochemical vocabulary).

Marking and designation

This section of the standard outlines both the mandatory and optional cell designation requirements that will apply to RNZB batteries and cells.

Cell designation (mandatory)

The mandatory markings will include letter-based markings that designate the rate of discharge characteristics of the cell in question. This designation will start with an RNZB specific letter(s) code. For example, in the case of sealed nickel-cadmium prismatic rechargeable single cells this is "KC". This will be followed by the rate of discharge designation lettering. For example, the following rate of discharge values are outlined in IEC 60623 for sealed nickel-cadmium prismatic rechargeable single cells:

- L – up to 0.5A
- M – up to 3.5A
- H – up to 7.0A
- X – up to and above 7.0A

Finally, the group of letters shall then be followed by a number indicative of the rated capacity of the cell in ampere-hours.

An example of the final cell mandatory designation for sealed nickel-cadmium prismatic rechargeable single cells is: KCH15. This corresponds to a cell of the previous stated type, with a discharge rating of up to 7.0A, and a rated capacity of 15 ampere-hours.

Cell designation (optional)
In the case that any markings would exceed the available space on the cell, it should be stated that the information may be omitted but shall be provided in the documentation corresponding to that particular cell and in the type test report.

Cell termination
It shall be decided if there are any specific cell termination marking or designation requirements. If there are then they shall be detailed in this section.

Marking
This section shall outline all the minimum required durable markings to be included on each cell or monobloc. This typically contains the following markings:

- The mandatory designation specified above.
- The name or other means of identifying the manufacturer or supplier.
- The positive terminal of the cell or monobloc (with reference made to IEC 60417)

Dimensions
Specific dimension data will be required in this RNZB specific document. A design drawing of the cells will be required, alongside a table providing the range of acceptable width, height, and length values for the particular RNZB cell type covered in this standard. Furthermore, any additional design information can be included in this section. Details regarding the measurement tolerances are also to be provided in this section of the document.

Electrical tests
A range of electrical tests specific to the cell in question are to be detailed in this section of the document. General charge and discharge currents for the tests outlined in this section are to be provided. These charge and discharge current values should be based on the rated capacity value of the cell undergoing the tests, with relevant formulas to be provided to allow the calculation of these currents. Any additional test requirements may also be detailed in this section.

The range of tests outlined in this section have been based on the requirements outlined in IEC 60622 and IEC 60623, which are specific to vented and sealed nickel-cadmium prismatic rechargeable single cells respectively. The specific tests, test conditions, test methodologies and acceptance criteria required for an RNZB cell specific document may differ from those presented by these examples.

Charging procedure for test purposes
In this section details regarding the specific procedure for charging the cells prior to testing are to be provided. This also includes the required discharging procedure prior to cell charging, with items such as the ambient temperature range, discharge current and final cell voltage being provided. The specific charging method(s) are to then be detailed, including but not limited to methods such as:

- Charging procedure based on constant current
- Charging procedure based on constant voltage at a given current
- Rapid charge current

Discharge performance

The required discharge performance of the cells under different conditions is to be provided in this section. Typically, the discharge performance at a range of temperatures is provided, alongside the specific test methodology and acceptance criteria for each of these tests. For each test, the cells are to be prepared as stated in the 'charging procedure for test purposes' section of this document. Any post-discharge test ambient temperature cell storage conditions and timelines are also to be detailed. Acceptance criteria typically include minimum cell discharge durations for a variety of rates of constant current discharges reaching defined final cell voltages. The results of this test will inform the rated discharge cell designation outlined in 'cell designation (mandatory)' section of this document.

These tests are typically completed for a range of temperature values relevant to the cell chemistry and type that is in question. The examples provided in IEC 60623 for vented nickel-cadmium prismatic rechargeable single cells include:

- Discharge performance at 20°C
- Discharge performance at +5°C
- Discharge performance at -18°C
- Discharge performance at low temperature – the temperature is expressed at 5°C intervals between -25°C and -40°C.
- Discharge performance at high temperature – the temperature is expressed at 5°C intervals between 30°C and 40°C.

Any other specific discharge condition tests may also be specified in this section of the document.

Charge retention

This test is aimed to verify the charge retention value of the cell in question. The test cells are to be charged in accordance with the requirements outlined in the 'charging for test procedures' section of this document.

This particular test typically requires that the cell is stored in an open circuit for a specified time period and held within a defined temperature range. Upon completion of this storage period, the cell is to be discharged in line with the requirements provided in the 'discharge performance' section of this document. A minimum discharge duration is to be defined in this section and used as the acceptance criteria for this test.

Endurance

Endurance testing is to be defined in this section of the document. The specific test conditions are to be provided including items such as the ambient temperature range and potential forced air draughting to maintain a defined cell electrolyte temperature range. Furthermore, it shall be stated that the cells are to be prepared for testing according to the 'charging procedure for test purposes' section of this document.

Specific endurance testing procedures are to be provided, including the specific charge and discharge conditions associated with each cycle of the endurance test. Any additional requirements applicable to the cycling test are also to be provided, such as potential resting periods between cycles or a lack thereof. The specific acceptance and test completion criteria are to be provided. Example criteria provided in the IEC 60623 document include the minimum number of cycles completed (500) and the specific discharge duration (3h 30min) of two successive cycles that signify that the endurance test is complete.

Charge acceptance at constant voltage

The requirement for the cells to be discharged in accordance with the requirements outlined in the 'charging procedure for test purposes' section of this document shall be stated. The charging criteria for this test are to be provided, including the ambient temperature requirements, the cell type, the charge voltage, the charge current, and the maximum charge time for each charge current. Furthermore, any post-charging storage conditions shall be provided, as well as the required discharge conditions and duration that act as the acceptance criteria for this test.

Electrolyte retention test

If electrolyte retention tests are required for the cell in question, this section shall contain the relevant test procedure and acceptance criteria shall be provided in this section of the report.

Storage

This section of the standard aim to verify the cells performance after a prolonged storage period (having been prepared for storage based on the manufacturer's instructions). The acceptable average ambient temperature range, relative humidity range, storage period and maximum ambient temperature values shall all be provided in this section. Acceptance criteria shall also be provided. In the example of IEC 60233, the cells are subjected to the discharge performance test at 20°C to verify their condition after the storage period is completed.

Additional electrical tests

Any other tests that are specific to the requirements of the cell in question can be included in this standard. This could include (but is not limited to) tests such as:

- Overcharge test
- Safety device operation
- Gas leakage test
- Short-circuit current and internal resistance

Mechanical tests

It is typical for no specific mechanical tests to be outlined in this standard, with mechanical tests being designed instead in relation to the intended application of the cell/battery. It should be stated in this section of the document that such tests should be the subject of agreement between the customer and the manufacturer.

Physical appearance

This section of the document should include a statement that defines the requirements for a visual inspection to be performed on the cells. Defects such as cracking, corrosion or other visual damages shall not be apparent. Furthermore, it should include the requirements for all dimensions to be within the tolerances specified within the manufacturer's drawings.

Type approval and acceptance

This section shall define the sample sizes and sequence of tests that are to be completed on the cells. The total number of cells required for the tests shall be stated, alongside the requirements for all cells tested to be new cells. The cells shall be separated into distinct groups, with the sample size, relevant clauses, tests, and allowable number of defective cells detailed for each of these groups. This is typically provided in the form of a 'Sequence of tests for type approval' table.

Batch acceptance details are also to be outlined in this section. These tests are applicable to deliveries of individual cells. A table including the recommended test sequence for the batch acceptance is typically provided in this section. This section shall state that these recommendations are to be followed unless otherwise agreed between

the supplier and the purchaser. It should also be stated that the sampling procedure used shall be established in accordance with IEC 60410.

5.1.2.3 Standard that specifies the recommended practice for maintenance, testing and replacement of specific vented RNZB stationary battery systems

In line with the example standards outlined in section 4.1.1.3, RNZB batteries will require the generation of a standard that provides recommendations for the installation, maintenance, and replacement of secondary RNZB batteries for use in standby stationary applications. This standard will also provide guidance for when RNZB batteries utilised in this specific use case will be replaced, as well as separate recommendations for use of RNZB batteries in renewable energy systems, such as photovoltaic and wind turbine systems. The overall aim of this document will be to provide the recommended practices that will enable an RNZB battery in a standby stationary application (and in a renewable energy system) optimised in terms of its performance and lifespan.

As outlined in sections 4.1.1.3.1, 4.1.1.3.2, and 4.1.1.3.3, a range of different recommendations are to be provided in this standard document. These main sections are outlined below:

- Safety aspects – Provide recommendations for the personal protective equipment and methods employed by maintenance and installation staff, as well as relevant precautions to be employed during this work.
- Installation design criteria – Specific installation location and mounting recommendations for RNZB batteries in this type of installation. Design recommendations regarding any battery specific hazards should also be provided in this section, as well as and requirements for instrumentation and alarms.
- Installation procedures – The recommended procedures for receiving and storing the battery should be provided, alongside recommendations for the battery assembly steps and the initial charging of the battery system.
- Maintenance – Inspection and corrective actions should be outlined in this section, with recommendations regarding the correct completion and implementation of these aspects provided.
- Test schedule – Recommendations for the performance and acceptance of a suitable battery test schedule should be detailed. Information relevant to the battery service and any potential modified performance information should also be included.
- The battery test procedure – The battery test procedure shall include all the initial conditions required to be applied to the battery system prior to testing. Test specific recommendations such as the test length and discharge rates shall also be included. Recommendations for the capacity test methods and procedures are to be outlined.
- Additional recommendations – Additional recommendations regarding the battery replacement criteria, battery recycling methods and any relevant appendices shall also be included in the document. The appendices may cover a wide range of topics, from specific RNZB information such as construction, charging voltage, electrolyte, and operating temperature, to the specific recommendations for operation within a renewable energy system. A wide range of examples of the typical appendices are provided in sections 4.1.1.3.1, 4.1.1.3.2, and 4.1.1.3.3.

5.1.2.4 Standard that specifies the recommended practice for personnel qualifications for installation and maintenance of stationary batteries

With the IEEE 1657 standard that outlines the main items that should be covered by training programs for stationary battery installation and maintenance personnel primarily applying to lead-acid and nickel-cadmium batteries, a similar standard (or adjustment to this existing standard) may be required to include RNZB batteries.

6 Conclusion

Based on a review of existing battery standards, with a focus on stationary battery energy storage applications, a summary of the main standards that the RNZB technology will need to adhere to has been provided. These standards have also been detailed further in the literature review section of this document, and are divided into the following main topics for ease of review:

- Standards related to safety requirements
- Standards related to performance requirements
- Key recycling and related marking legislation and standards
- Standards that specify the testing requirements of cells and batteries

It is noted that whilst the are no existing standards for RNZB batteries, the nickel-cadmium technology is the most similar technology in terms of battery chemistry and cell structure. As a result, existing nickel-cadmium standards have been an important form of reference to direct the future standardisation of the RNZB technology. Based on a review of existing technology-specific standards (including nickel-cadmium and other battery technologies), the main topics that are likely to form the basis of future RNZB standardisation activities include:

- A standard that specifies any technology-specific safety considerations for RNZB cells and batteries and their use in battery systems or installations
- A standard that specifies the marking, tests, and requirements for secondary RNZB batteries.
- A standard that specifies the recommended practice for maintenance, testing and replacement of specific vented RNZB stationary battery systems
- A standard that specifies the recommended practice for personnel qualifications for installation and maintenance of stationary batteries

Many of these standards include direct references to the information that is required to be supplied by the battery manufacturer. It has been identified that the manufacturer's documentation should include the following battery-specific information:

- Voltage and current limits
- Charging and rest periods
- Operating temperature information
- Safety instructions related to the potential hazards associated with the battery technology
- Cell and battery transport documentation
- Battery system installation and commissioning documentation
- Battery system operating and maintenance documentation
- Documentation relevant to battery system decommissioning and cell disposal

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