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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Environmental Engineering (EE).

The present document is part 2 of a multi-part deliverable covering Innovative energy storage technology for stationary use, as identified below:

Part 1: "Overview";

Part 2: "Battery";

Part 3: "Supercapacitor".

Modal verbs terminology

In the present document "**shall**", "**shall not**", "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The present document is a part (Part 2: Battery) of a series of standards (the other standards in the series being ETSI TS 103 553-1 [1] and ETSI TS 103 553-3 [i.19] on innovative energy storage systems for stationary power systems of telecom/Information and Communication Technology (ICT) equipment used in telecom networks, data centres and Customer Premises Equipment (CPE). The present document introduces technologies and methods for evaluating, selecting and testing battery systems for defined applications.

Introduction

Conventional Valve Regulated Lead Acid (VRLA) batteries are widely used for their low cost, mature technology and infrequent and easy maintenance. However, with the continuous development of broadband network technologies (wireless base stations or optical access sites) associated with higher energy density core network sites and data centres, traditional bulky batteries are gradually exposed to higher ambient temperatures and other stresses.

As alternatives, new battery technologies may provide better performances in size, weight, temperature range, cycling, high-rate charging and discharging, environmental protection and many other advantages.

Other applications of stationary rechargeable batteries are now observed for resilience of customer home or office telecom/ICT installations, that can be associated with renewable energy sources in countries with unstable AC grids. More recently new requirements for uninterrupted power for Internet of Things (IoT) and Machine to Machine (M2M) devices have also emerged using rechargeable batteries rather than primary batteries due to advantages in size, costs and issues of replacement frequency.

However as discussed in IEEE Intelec2018 [i.23], the increasing demands on stationary batteries are driving innovation and many new battery technologies are being developed. Consequently there is a need for a method to discriminate the most appropriate technologies and products for one or several applications and for this purpose additional evaluations and tests are still required.

The present document introduces basic requirements and tests methods for evaluating new batteries (lithium, nickel based, etc.) for stationary use in power supply systems of ICT equipment. The present document also complements existing general International Electrotechnical Commission (IEC) standards of electrochemical battery products.

In each family of technologies, a typical chemistry is taken as a basis for improved description, e.g. lithium iron phosphate is in the lithium battery family, nickel-zinc is in the nickel based family, etc.

The present document was developed jointly by ETSI TC EE and ITU-T Study Group 5 and is published respectively by ITU and ETSI as Recommendation ITU-T L.1221 [i.17] and the present document, which are technically equivalent.

1 Scope

The present document contains the main requirements for evaluating appropriate innovative batteries for stationary use for powering ICT equipment in telecom sites, active network units and data centres or customer premises with standardized power interfaces in -48 V, up to 400 VDC or 12 V.

Based on the general selection and evaluation method proposed in ETSI TS 103 553-1 [1], the present document introduces the main battery technologies, characteristics and the method to select, evaluate and test battery products adapted to a defined application.

The present document describes the selection criteria and possible tests for making the appropriate or optimal choice of battery technology for an ICT stationary application. This includes mechanical performance, electrical performance, (voltage, current, power and capacity ratings, efficiency and self-discharge, etc.), environmental performance (temperature range), lifetime performance (cycling and calendar life, tolerance of partial charge and depth of discharge), installation, operation and maintenance complexity (parallel operation), safety (risk to and protection of humans and environment, error and fault tolerance), management/monitoring (including anti-theft solution) at battery and cell level and Total Cost Ownership (TCO) assessment.

The present document specifies evaluation methods and tests which complement those of existing relevant standards requirements.

2 References

2.1 Normative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at https://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are necessary for the application of the present document.

[1] ETSI TS 103 553-1: "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 1: Overview".

[2] ETSI ES 202 336-11 (V1.1.1) (2014): "Environmental Engineering (EE); Monitoring and control interface for infrastructure equipment (Power, Cooling and environment systems used in telecommunication networks); Part 11: Battery system with integrated control and monitoring information model".

[3] IEC 60896-21:2004: "Stationary lead-acid batteries - Part 21: Valve regulated types - Methods of test".

[4] IEC 60896-22:2004: "Stationary lead-acid batteries - Part 22: Valve regulated types - Requirements".

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] Recommendation ITU-T L.1001 (2012): "External universal power adapter solutions for stationary information and communication technology devices".

[i.2] Recommendation ITU-T L.1200 (2012): "Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment".

[i.3] Recommendation ITU-T L.1201 (2014): "Architecture of power feeding systems of up to 400 VDC".

[i.4] ETSI ES 203 474: "Environmental Engineering (EE); Interfacing of renewable energy or distributed power sources to 400 VDC distribution systems powering Information and Communication Technology (ICT) equipment".

[i.5] ISO/IEC 17025 (2017): "General requirements for the competence of testing and calibration laboratories".

[i.6] IEC 62619 (2017): "Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications".

[i.7] IEC 61960-3 (2017): "Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for portable applications - Part 3: Prismatic and cylindrical lithium secondary cells and batteries made from them".

[i.8] UN38.3 (ed.5 amendment 1): "Recommendations on the TRANSPORT OF DANGEROUS GOODS - Manual of Tests and Criteria".

[i.9] Translated from Chinese Standard (GBT 2423.17-2008, GB/T2423.17-2008, GBT2423.17-2008): "Environmental Testing for Electric and Electronic Products - Part 2: Test Methods - Test Ka: Salt Mist".

[i.10] IEC 60068-2-11 (1981): "Basic environmental testing procedures - Part 2-11: Tests - Test Ka: Salt mist".

[i.11] ETSI EN 300 132-2: "Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 2: Operated by -48 V direct current (dc)".

[i.12] ETSI EN 300 132-3-1 (2012): "Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 3: Operated by rectified current source, alternating current source or direct current source up to 400 V; Sub-part 1: Direct current source up to 400 V".

[i.13] ETSI TR 103 229 (2014): "Environmental Engineering (EE) Safety Extra Low Voltage (SELV) DC power supply network for ICT devices with energy storage and grid or renewable energy sources options".

[i.14] ETSI TR 102 532 (V1.1.1) (2009-06): "Environmental Engineering (EE) The use of alternative energy sources in telecommunication installations".

[i.15] The European Association for Advanced Rechargeable Batteries Roadmap (2013): "E-mobility Roadmap for the EU battery industry".

[i.16] IEC 60050-482 (2004): "International Electrotechnical Vocabulary - Part 482: Primary and secondary cells and batteries".

[i.17] Recommendation ITU-T L.1221: "Innovative energy storage technology for stationary use; Part 2: Battery".

[i.18] IEC 62620: "Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications".

[i.19] ETSI TS 103 553-3: "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 3: Supercapacitor".

[i.20] Recommendation ITU-T L.1205(2016): Interfacing of renewable energy or distributed power sources to up to 400 VDC power feeding systems.

[i.21] SooGREEN European Project (2016-2018): "Service-oriented optimization of Green mobile networks", Invited paper, Rocha et alii.et alii Orange, Nokia, KTH, Royal Institute of Technology Netherland, Electrum Tele2 Sweden, Institut Mines Telecom, France, Eurico Ferreira Portugal, 2017.

NOTE: Available at http://opendl.ifip-tc6.org/db/conf/wiopt/wiopt2017/1570349026.pdf.

[i.22] David Linden, Thomas B. Reddy: "Handbook of batteries-4th edition Library of Congress Cataloging-in-Publication Data".

[i.23] D. Marquet et alii Orange, C. Campion (3C projects): "How to transform innovative battery opportunities in field operational solutions for Telecom/IT application IEEE Intelec 2018", Torino.

[i.24] IEC 60896-11:2002: "Stationary lead-acid batteries - Part 11: Vented types - General requirements and methods of tests".

[i.25] IEC 61427-1: "Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application".

[i.26] EUROBAT 2015.

[i.27] IEC 62485-2: "Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries".

[i.28] IEC 62259: "Secondary cells and batteries containing alkaline or other non-acid electrolytes - Nickel-cadmium prismatic secondary single cells with partial gas recombination".

[i.29] IEC 61434: "Secondary cells and batteries containing alkaline or other non-acid electrolytes - Guide to designation of current in alkaline secondary cell and battery standards".

[i.30] IEC 60623: "Secondary cells and batteries containing alkaline or other non-acid electrolytes - Vented nickel-cadmium prismatic rechargeable single cells".

3 Definition of terms, symbols and abbreviations

3.1 Terms

For the purposes of the present document, the following terms apply:

Battery Management System or Unit (BMS, BMU): electronic system associated with a battery which monitors and/or manages its state, calculates secondary data, reports that data and/or controls its environment to influence the battery's performance and service life and has the functions to cut off in case of abnormal conditions (e.g. over charging, over current and over heating and charge balancing between cells or parallel cells blocks)

NOTE 1: Depending on the application and its size, the function of the BMS/BMU can be assigned to the battery cell, module, string, pack or system and equipment using the battery. A common implementation is a BMS/BMU made of several electronic modules located at different levels of the system.

NOTE 2: A Battery Management System (BMS) is sometimes also referred to as a Battery Management Unit (BMU).

NOTE 3: Definition adapted from IEC 60050-482 [i.16] and IEC 62620 [i.18].

battery module: group of cells or blocks connected together either in a series and/or parallel configuration with or without protective devices (e.g. fuse or PTC) and electronic circuitry

NOTE 1: Typically, this is parallel/serial arrangement of small cylindrical e.g. Lithium-ion or Ni based cells often named mSnP module.

NOTE 2: Definition adapted from IEC 60050-482 [i.16] and IEC 62620 [i.18].

battery pack: energy storage device, which is comprised one or more cells or modules electrically connected together inside a mechanical pack with electronics as required for safety and operation

NOTE 1: The battery pack may incorporate a protective housing and be provided with terminals or other interconnection arrangement. It may include protective devices and control and monitoring required for safe and proper operation. A typical example of a battery pack may be built by using 6s2p Lithium-ion module. It may provide detailed information (e.g. cell voltage, temperature, capacity) to a higher level battery system management device.

NOTE 2: Definition adapted from IEC 60050-482 [i.16] and IEC 62620 [i.18].

battery string: group of cells or battery modules of same technology and capacity connected in series to match the battery system voltage

NOTE: Strings can work in parallel with or without protective device (e.g. fuse or PTC) depending on the technology and safety risk.

battery system: system which incorporates one or more battery cells, modules, strings or battery packs and has one or more BMS or BMU

NOTE 1: The battery system is generally defined for high power and capacity batteries made of several battery strings or packs of blocks or modules it may include cooling or heating units and gas exhaust arrangement.

NOTE 2: Definition adapted from IEC 60050-482 [i.16] and IEC 62620 [i.18].

cell, accumulator cell: cell where electrical energy is accumulated by electrochemical reactions between the negative electrode and the positive electrode

NOTE: Definition adapted from IEC 60050-482 [i.16] and IEC 62620 [i.18].

cells block: group of cells connected together in parallel configuration with or without protective devices (e.g. fuse or PTC) and electronic circuitry, generally not ready for use as battery system as not yet fitted with its final housing, terminals arrangement, etc.

NOTE 1: Typically, this is parallel arrangement of n small cells e.g. Lithium-ion or Ni based cells often named nP configuration.

NOTE 2: Definition adapted from IEC 60050-482 [i.16] and IEC 62620 [i.18].

charge recovery: charge capacity (generally in Ah) that a cell or battery can deliver after the charge following the charge retention test

NOTE: As defined in IEC 62620 [i.18].

charge retention: charge capacity (generally in Ah) that a cell or battery can deliver after storage, at a specific temperature, for a specific time without subsequent recharge as a percentage of the rated capacity

NOTE: As defined in IEC 62620 [i.18].

cumulative discharging energy (kWh): discharging energy (kWh) in the whole cycle life ending at a defined remaining capacity e.g. 70 % of rated capacity under defined normal working condition (including the working temperature, charging and discharging rate, and DoD)

end-of-discharge voltage: specified closed circuit voltage at which the discharge of a cell or battery is defined as terminated by the manufacturer

NOTE: Definition adapted from IEC 60050-482] [i.16] and IEC 62620 [i.18].

genset: generator producing electricity by using fuel e.g. a diesel generator

NOTE: When associated with a battery system in a Hybrid Genset Battery (HGB) system the system energy efficiency is optimized and thus the fuel consumption to produce the same electrical HGB system output is reduced.

nickel based battery: aqueous battery that uses nickel metal and hydroxide in electrodes such NiFe, NiCd, NiMH and NiZn batteries

nominal voltage: suitable approximate value of the voltage used to designate or identify a cell or a battery

NOTE 1: The cell or battery manufacturer may provide the nominal voltage.

NOTE 2: The nominal voltage of a battery of n series connected cells is equal to n times the nominal voltage of a single cell.

NOTE 3: As defined in IEC 62620 [i.18].

rated capacity: capacity value of a cell or battery determined under specified conditions and declared by the manufacturer

NOTE 1: The rated capacity is the quantity of electricity Cn Ah (ampere-hours) declared by the manufacturer which a single cell or battery can deliver during a period of n hours when charging, storing and discharging under specified conditions by the manufacturer.

NOTE 2: As defined in IEC 62620 [i.18].

3.2 Symbols

For the purposes of the present document, the following symbols apply:

A ICT equipment power feeding interface of -48 VDC
A3 ICT equipment power feeding interface of up to 400 VDC

NOTE: As defined in Recommendation ITU-T L.1200 [i.2].

$\mathbf{C_n}$ Battery capacity in Ah in n hours discharge rate
$\mathbf{I_n}$ Battery discharge current in n hours discharge rate

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AC Alternating Current
AGM Absorbent Glass Mat
Ah Ampere hour
B Battery Block
BMS Battery Management System
BMU Battery Management Unit
BMU (B) Battery Management Unit (Block)
BMU (M) Battery Management Unit (Module)
BMU (S) Battery Management Unit (String)
BS Battery System
CAPEX Capital Expenditure
CPE Customer Premises Equipment
DC Direct Current
DoD Depth of Discharge
E Evaluation
EoL End of Life
EUT Equipment Under Test
HARB Hybrid Aqueous Rechargeable Battery
HGB Hybrid Genset Battery system
ICT Information and Communication Technology
IoT Internet of Things
LA Lead-Acid
LCO Lithium Cobalt Oxide
LFP Lithium Iron Phosphate
LMO Lithium Manganese Oxide

LTO	Lithium Titanate Oxide
M	Module
M2M	Machine to Machine
NCA	Nickel Cobalt Aluminium
NCM	Nickel Cobalt Manganese
NiCd	Nickel Cadmium
NiFe	Nickel Fer (Nickel-Iron in English)
NiMH	Nickel Metal Hydride
NiZn	Nickel Zinc
NMC	Nickel Manganese Cobalt
OPEX	Operational Expenditure
OPZS	Ortsfest (stationary) PanZerplatte (tubular plate) Flüssig (flooded)
OPZV	Ortsfest (stationary) PanZerplatte (tubular plate) Verschlossen (closed)
PbC	Lead-Carbon
PSoC	Partial State of Charge
PSU	Power Supply Unit
PTC	Positive Temperature Coefficient resistor
PV	PhotoVoltaic
RES	Renewable Energy System
S	System
SCPS	SCPS laboratory
SELV	Safety Extra Low Voltage
SoC	State of Charge
SoH	State of Health
T	Test
TCO	Total Cost Ownership
U	Unit
UPS	Uninterrupted Power Supply
VDC	Volt Direct Current
VRLA	Valve Regulated Lead Acid
Wh	Watt hour

4 Battery configurations and stationary applications

A battery is an assembly of cells contained in a more or less sealed jar made of:

- negative and positive electrodes having active material on electric collectors;
- separator between the electrode making galvanic insulation and containing ionic electrolyte;
- electrolyte allowing the movement of ions making the electric charge/discharge reactions (the electrolyte can change its nature or not during the change of charge of the cell);
- electrical connection from interior to exterior of the jar from soldered set of negative and positive electrodes to external poles.

Figure 1 shows some examples of battery cell structures. Some of these battery cells can be used both in stationary and in mobile applications. Many battery cell structures, such as the common cylindrical cells, can be found in Linden [i.22] and in Roadmap 2013 [i.15].

Internal structure of Lithium-ion Battery

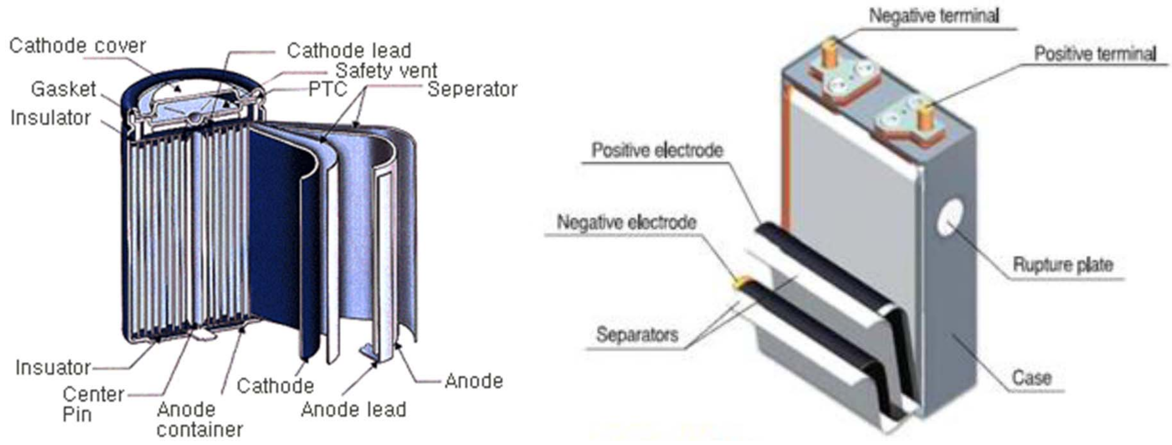


Figure 1:Typical constitution of cylindrical and prismatic Lithium-ion cell

The stationary batteries are used for stationary application of power supplies of ICT equipment in telecom sites or active network units, data centres or customer premises with standardized power interfaces in -48 V ETSI EN 300 132-2 [i.11], up to 400 VDC [i.2] or ETSI EN 300 132-3-1 [i.12], or other voltages such as 12 V as defined in Recommendation ITU-T L.1201 [i.3] for stationary use telecom termination devices.

The use modes include:

- back-up of electric grids of different quality;
- cycling use on intermittent public grids or Renewable Energy Systems (RESs) or engine generator sets (HGB);
- peak power shaving to reduce permanent power sizing of power supplies or remote lines.

Typical applications are as follows:

- telecom rectifier-battery DC systems;
- AC Uninterrupted Power Supply (UPS);
- renewable energy systems with charge-controller between generator, battery and load as presented in Recommendation ITU-T L.1205 [i.20], ETSI ES 203 474 [i.4] and also in ETSI TR 102 532 [i.14];
- hybrid engine generator set with battery (HGB);
- power supply with back-up for fixed terminals;
- peak power shaving;
- Customer Premises Equipment (CPE) back-up network in a Safety Extra Low Voltage (SELV) circuit as presented in ETSI TR 103 229 [i.13].

Typical implementation examples are given in Annex A.

5 Overview of battery technologies

5.1 Types of technologies

There are many types of battery technologies.

The main ones are:

- Aqueous ionic electrolyte:
    - Acid:
        - Lead:
            - Flooded or vented Lead-Acid (LA)
            - VRLA type
            - Lead-carbon (PbC)
            - Pure lead, bipolar LA
        - Other metal acid batteries.
    - Alkaline:
        - Nickel based:

            NiFe

            NiCd

            NiZn

            NiMH

            (NiMn, NiNi in research state)
    - Neutral salt:
        - Flow battery (vanadium, iron-boron, iron-iron, etc.)
        - Sodium sulfate, etc.
        - Metal-air (zinc, aluminium, magnesium, calcium other alloys, etc.)
- Non aqueous electrolyte (organic or low temperature solid) works by an insertion mechanism (change of solid oxide crystal charge with ion insertion or intercalation rather than aqueous reduction/oxidation of metal/ion couples):
    - Lithium-ion (LCO, LMO, NCA, NMC, LFP, LTO)
    - metal-air (lithium, sodium, potassium, other alloys, etc.)
- Hybrid Aqueous Rechargeable Battery (HARB) that uses both mechanisms (aqueous oxydo-reduction and ion insertion). It may apply to aluminium-ion or zinc-ion solutions.
- Hot temperature solid (metal electrodes and melted salt electrolytes):
    - hot temperature: nickel chloride-sodium, sodium-sulfur operating at much higher temperature than ambient temperature with some melted material inside (e.g. sodium or sulfur at higher temperatures than 150 °C).
- Solutions with other separation mechanisms (e.g. by gravity) such as liquid bi-metal medium temperature alloy battery are under research.

NOTE: The initial edition of the present document will not cover all the technologies emerging from recent intensive research related to electric vehicles and renewable energy storage, but many considerations and evaluation methods defined within, such as electrical characterization for an application, are applicable.

5.2 Lithium ion battery cells

5.2.1 Cell types

There are two types of lithium ion battery cells, these are known as hard case and soft case types.

The hard case types are typically of cylindrical or prismatic case type. The soft case type is a pouch.

In terms of the cathode and anode material, several types exist:

- For the cathode material: LCO, LMO, NCA, NMC, LFP, lithium-metal, etc.
- For the anode material: Graphite and LTO type, etc.

NOTE 1: Lithium metal cells have in general a solid electrolyte separator ensuring safety, but requiring operation at higher than ambient temperature for improving electrical conductivity and output power. Due to heating, energy efficiency is lower than on lithium-ion cell operating at ambient temperature.

NOTE 2: New aluminium, sodium, magnesium and potassium ion cells could provide a low cost alternative to lithium-ion for stationary applications where the highest energy density is not required, if they prove to be safe, reliable and use very few rare materials.

5.2.2 Characteristics of lithium ion battery cells

The lithium ion battery cells have the following main characteristics:

- High gravimetric and volumetric energy density
- Higher voltage than aqueous technologies (> 2 V)
- No memory effect and negative effect of Partial State of Charge (PSoC)
- Moderate environmental impact depending on chemical composition and features (less cobalt, less toxic electrolyte, better recycling)
- High rate discharge
- Fast charge and long life cycle
- Safety
- Wide temperature ranges

NOTE: For some lithium technologies, permanent high State of Charge (SoC) and high voltage can accelerate ageing effect compared to Partial State of Charge (PSoC).

5.2.3 Nominal voltage of lithium ion battery cells

Lithium-ion technologies used in portable devices can be used as a stationary battery and have a well-known high nominal voltage of 3,6 V. Annex C lists standard secondary lithium cells defined in IEC 61960-3 [i.7].

Battery manufacturers are developing technologies to increase the nominal voltage to 3,7 V or 3,8 V in order to increase the energy density enabling market for mobility and portable devices. However the nominal voltage varies depending on the cathode and anode material chemical composition and some technologies that have a lower voltage are targeting high capacity for stationary energy storage applications requiring high safety, long lifetime and good TCO. Here weight and volume performances are less critical than for mobile applications.

Table 1 shows the nominal voltages for different cathode or anode materials.

Table 1: Nominal voltage for cathode or anode materials

Cathode/Anode material	Nominal voltage (V)
LCO	3,8
LMO	3,8
NMC	3,7
NCA	3,6
LFP (LiFePO4)	3,2
LTO	2,2

5.2.4 End-of-charge and end-of-discharge voltage

Since lithium ion batteries present the possibility for violent fire in the case of over-charging or over-discharging, safety is a key consideration. For lithium iron phosphate batteries the nominal voltage is commonly 3,2 V, with end-of-charge and end-of-discharge voltage at ±0,5 V of the nominal value, i.e. 3,7 V and 2,7 V, respectively.

Voltage range is also of high importance when using them directly with telecom/ICT equipment standardized interfaces. For example a -48 V interface ETSI EN 300 132-2 [i.11] specifies a voltage range of 40,5 V to 57 V at input of equipment. The voltage range of an output power plant is defined by the operator, e.g. 43 V to 57 V.

This imposes the use of 24 lead-acid cells in a battery string, where each cell operates within a 1,8 V to 2,3 V voltage range.

With lithium it is more complex as the battery voltage range has been historically defined for lead-acid batteries and because lithium cells have a lot of different chemical compositions leading to different cell voltage ranges.

Some examples of configuration design are illustrated in the case of lithium iron phosphate (LFP) technology:

- 16 cells and uses a wide cell voltage range 2,7 V to 3,7 V:
  - min voltage = 2,7 × 16 = 43,2 V
  - max voltage = 3,7 × 16 = 59,2 V. This is too high to comply with ETSI EN 300 132-2 [i.11]

A solution for direct connection of 16 cells to the load is possible by working at PSoC below 100 % charge level as should accepted by lithium; in that case the maximum cell voltage is 3,55 V and max voltage is 56,8 V.

- 15 cells and using wide cell voltage range 2,7 V to 3,7 V:
  - min voltage = 2,7 × 15 = 40,5 V. This is too low to comply with ETSI EN 300 132-2 [i.11]
  - max voltage =3,7 × 15 = 55,5 V

One solution is to increase the end of discharge which reduces the useful Depth of Discharge (DoD) and thus capacity. Another solution is a step-up or boost converter inside the battery or outside the battery to reduce the voltage range and stay inside the -48 V voltage range as defined in ETSI EN 300 132-2 [i.11] at input of ICT equipment.

NOTE 1: The step up converter provides a constant output voltage within the voltage range defined in ETSI EN 300 132-2 [i.11]. The higher voltage up to 57 V can reduce the power loss on the cable and achieve a longer autonomy when supplying power to telecom power load (e.g. 2 kW) over long distances (e.g. 50 - 100 metres).

NOTE 2: The risk of unavailability due to failure of the boost converter is limited if it can be by-passed when using a battery with a voltage range partially matching the load voltage range input. The converter cost could be balanced by energy saving and using in ICT equipment Power Supply Unit (PSU) with narrow voltage ranges.

5.3 Some innovative aqueous Nickel based batteries with no heavy metals

5.3.1 Cell types

The nickel based NiMH and NiZn batteries exist in hard case cylindrical and prismatic cells and can work in valve regulated type as VRLA in the case of lead acid batteries.

For NiZn, it is possible to remove the valve and exceptionally refill them with demineralized water to increase their life time.

In terms of the material and mechanical type of cathode and anode, there exist several types depending on:

- Additives in electrodes (cobalt, rare earths, etc.).
- Mechanical electrode structure: conductive metallic foam collectors receiving active material, metallic pockets, fritted material on metallic plate collectors.

5.3.2 Characteristics of NiMH or NiZn battery cells

The NiMH and NiZn cells and batteries have the following main characteristics:

- Higher gravimetric and volumetric energy density than lead-acid or NiCd sufficient for stationary telecom applications, relatively lower voltage than non-aqueous technologies (< 2 V).
- Very safe solution with no highly reactive or toxic materials allowing easy manufacturing and recycling. As for lead-acid battery a simple aeration is sufficient to avoid any risky hydrogen accumulation in the case of overcharging.
- Almost no memory effect and negative effect of Partial State of Charge (PSoC).
- Very high power charge and discharge ratings.
- Long life time and life cycle performance.
- Wide temperature range.
- Higher reliability and stress tolerance than lithium or lead-acid.
- No need of accurate BMS at cell level for safety; a simple BMS improves charge balancing.

NOTE 1: The 'green solution' factor and the low cost of materials and of manufacturing are often claimed for NiFe and zinc based solutions such as NiZn or zinc-air.

NOTE 2: NiFe and NiCd have higher tolerance to stress than NiMH or NiZn. NiFe is often claimed as the more robust and of having a longer lifetime but NiFe consumes lot of water and has low energy density. NiCd has lower energy density than NiMH or NiZn and requires very strict procedures in manufacturing and end of life accurate management due to cadmium toxicity similar to other heavy metals such as lead.

5.3.3 Nominal voltage and voltage range of Nickel based battery cells

Table 2 gives the nominal voltage of nickel based batteries in industrial production and examples of battery configurations adapted to -48 V ETSI voltage range defined in ETSI EN 300 132-2 [i.11].

The voltage range corresponds to cells adapted for 1 hour discharge time.

Table 2: Nominal voltage for cathode or anode material

Ni technology	Nominal voltage (V)	Number of serial cells for Telecom/ICT equipment range (V)	Adapted voltage range
NiFe	1,2	40	1,1 to 1,43
NiCd	1,25	38	1,15 to 1,5
NiMH	1,25	38	1,15 to 1,5
NiZn	1,65	30	1,4 to 1,9
NOTE: A boost converter could also be used with same comment on unavailability and cost as in note of clause 5.2.4.			

5.4 Typical configuration of a battery system

5.4.1 General configuration of a battery system

The basic structure of the battery system for a stationary telecom/ICT application with cells management uses a battery management system as shown in the example in Figure 2.

The power source feeds energy to load and to charge the battery. The battery can also feed power when discharging and when the power source is not working.

Different nominal battery voltages are possible for different feed voltages:

- -48 V range for compliance with interface A defined in ETSI EN 300 132-2 [i.11].
- Up to 400 VDC for compliance with interface A3 defined in Recommendation ITU-T L.1200 [i.2] and ETSI EN 300 132-3-1 [i.12].
- UPS battery at different DC voltages. Generally it depends on the power, solution and can have nominal values in the range 12 V to 700 V.
- Small batteries in a stationary device power supply ensuring compliance to 5 or 12 V outputs of Recommendation ITU-T L.1001 [i.1] are a specific small case of DC UPS.

The battery system consists of two main parts:

- battery cells or cells blocks arranged in modules composing strings or packs;
- BMS or BMU electronic functions associated with electrochemical cells for safe and performance operation.

The battery system shall have a control/monitoring interface with the minimum set of information defined in ETSI ES 202 336-11 [2] for interoperability of all the power, cooling, building infrastructure and equipment energy metering in telecom installations and data centres.

5.4.2 Battery Management System and Unit (BMS/BMU)

Regarding the BMS (sometimes called BMU) functions, in general global charge and discharge management is required for safe operation and maintenance in order to avoid over or under charge, by controlling voltage and current and temperature. Time control is also used in different charging modes when required (e.g. to avoid over-charge and over-heating).

NOTE 1: The management at system level is usually called BMS and management at unit levels (cabinets, modules, blocks) is called BMU.

Some battery technologies require additional accurate limitation of each cell voltage and cell temperature. The cell temperature does not need be detected on any single cell but just in certain area to ensure the integral safety of cell, blocks or pack.

These are part of a BMS function and shall be of high reliability to avoid any internal cell failure resulting in toxic smoke or fire risk.

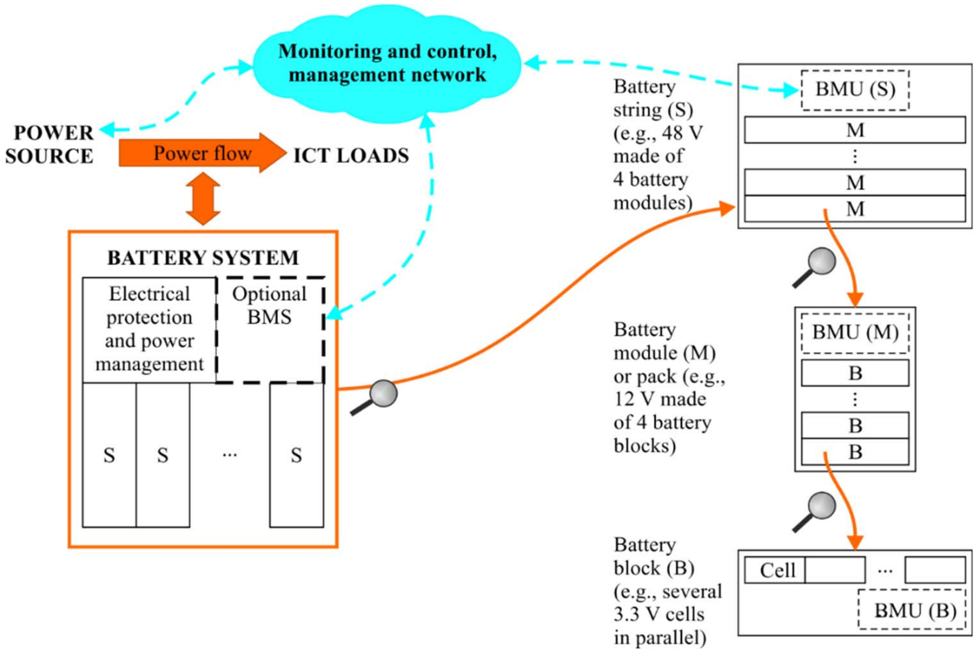
For aqueous technology, the risks are different and do not require individual cell electrical and thermal parameters monitoring (e.g. enough ventilation to avoid explosive hydrogen concentration, anti-projection cork avoiding corrosive electrolyte, etc.)

Cell balancing is also required for some technologies. For lead-acid and some nickel based technologies or hot batteries such as sodium based batteries, the balance between cells is obtained at module or pack level, e.g. by boosting the whole battery string voltage.

In general, for lithium and some other technologies it shall be done at cell or parallel cells block level.

In practical implementations, the BMS/BMU when required for safe and performance operation can be obtained by electronic control units at different levels as shown in the example of Figure 2:

- battery system BMS
- battery string or pack BMU (S)
- battery module BMU (M)
- cell blocks BMU (B)



NOTE: All BMS/BMU are in dotted lines as they depend on cell technology and manufacturing options. For example, the BMU(M) and BMU(B) functions can be all achieved by the BMU(S).

Figure 2: Typical battery system structure used in a rectifier-battery DC power system

When it exists the following parameters shall be monitored and/or controlled by the different BMS or BMU for safe and performance operation:

- the voltage limits of each cell
- the voltage and current limits of the whole battery
- the temperature limit of the whole battery
- the temperature of a certain number of points inside the battery

NOTE 2: Depending on the arrangement of the system it can be possible to monitor/control the current inside each string, pack or module as it provides an indication of the current balance between them. In the case of Li-ion batteries, the BMS can manage the charge or voltage balancing of the cells in a string of cells in series e.g. inside a module.

NOTE 3: For example, a BMS can apply a balancing current of 200 mA, with a balancing time range of 10 to 120 min in order to maintain the cell voltage difference at lower than 10 mV and the cell balancing function can balance 4 battery cells at the same time.

NOTE 4: The higher the balancing current, the bigger the capacity dispersion it can compensate and the shorter the balancing time. The BMS Li-ion battery system can include other important engineering and operation features.

Self-management

As the Li-ion battery vendor can be different from the vendors' power systems, it should operate independently of the vendors' power system or require no complex battery parameter settings during capacity expansion.

Parallel operation

The connection of battery groups for power or autonomy expansion can be done with Li-ion batteries from different manufactures connected in parallel with a defined discharge power limit (e.g. 5 kW output power).

The Li-ion battery should be with no output derating when used in parallel mode.

NOTE 5: E.g. if one 48 V Li-ion battery module maximum discharge current is 50 A, when paralleled with other types of battery, the maximum discharge current of the Li-ion battery should be the same i.e. 50 A in this case.

When all batteries are from the same vendor a sufficient backup time can be achieved simply by adding batteries for power expansion. The power expansion of Li-ion batteries in parallel should be with no output power derating.

There is no need to deploy one set of power system batteries for every power unit to supply a large-power site or a site of a tower company.

NOTE 6: For example, the maximum output power of Li-ion battery in parallel can reach 15 kW, as the macro site power consumption or tower company site grows to more than 10 kW. The quantity N of Li-ion battery groups can reach 32 groups connected in parallel to provide higher power. This simplifies capacity expansion and considerably reduces the Capital Expenditure (CAPEX) and Operational Expenditure (OPEX).

The maximum output power of Li-ion battery groups (Pn) can be calculated as follows:

$$Pn=N \times Ps$$

Where:

- N is the quantity of Li-ion 48 V battery groups
- Ps is the maximum output power of single Li-ion battery group

When at least one battery group in the N battery groups discharge to 100 % DoD, the other batteries should be able to provide the full power providing enough redundancy (e.g. with N+1 battery groups or some overload capacity.)

Mixed hybrid battery technology use option

The Li-ion battery can be used with any batteries of different types and ages connected in parallel. This feature may maximize the residual value of legacy batteries and reduce the system CAPEX and OPEX.

Software lock option and antitheft function

After disconnecting the Li-ion battery from the power system controller, the Li-ion battery is locked and cannot be charged or discharged after a defined time (e.g. 72 hours by default and configurable in the range of 8 hours to 720 hours). In addition, an unlock function is needed when required.

Annex H details some considerations on public key infrastructure development.

6 Technology evaluation and tests

The evaluation methods and tests of batteries to be carried out shall be defined based on the ETSI TS 103 553-1 [1] method chart for preselection of battery products and tests for some defined applications. The approach is specified in the following steps:

- **Step 1:** Define the user specifications i.e. based on Table 3, define the selection criteria for the applications under consideration and select those required for each application, including its weight. The rows in Table 3, which is referred to as the T_spec, list the selection criteria, and the columns list the applications. Table F.1 in Annex F shows an example of a completed (filled-in) specification table.

NOTE 1: This specification table (T_spec) gives only a general review of criteria for typical selected applications but new columns and rows might be defined for other applications. The criteria is a feature with a severity level e.g. efficiency > 80 %, cycling performance at 50 % DoD at 35 °C > 4 000 cycles.

NOTE 2: Examples of applications are a solar station, a grid back-up (with more or less cycling) and weight/volume constraints (floor, roof or mast top), a HGB system, smartgrid services, customer home, diesel starting system, street cabinet, UPS, etc.

- **Step 2:** Preselect the presumed adapted battery technologies using knowledge bases from manufacturers and other users' information (standards, performances, environmental aspects, costs) regarding the criteria defined and selected in T_spec (Table 3) for each application. Based on this, create the matching table (T_match), shown in Table 4, for each application.

NOTE 3: Criteria are reported in the rows and technologies in the columns.

NOTE 4: The cost analysis should include a TCO approach.

- **Step 3:** Complete the T_match table (Table 4) with available information and evaluation or test results and quote matching score of the preselected technologies for each defined criteria to get the global score for each battery technology.

If a matching criteria is not considered sufficient, define which complementary evaluation and tests are required and the work plan for completing a reasonably fast evaluation as battery tests can be very heavy and long lasting. It is also possible to change a product or specification and requirement based on result analysis and difficulty in finding solutions.

NOTE 5: When more than one application is considered, there will be one table per application and, if required, it is possible to try to find a common battery technology for several applications.

In step 3 the work plan would consist in general of:

- relatively short tests of some weeks or months (operation and stress tests at normal, extreme and abusive electrical and thermal conditions) as defined in ETSI TS 103 553-1 [1];
- long tests such as cycling, back-up, storage self-discharge, etc., over 1 or 2 years;
- tests on cells and on battery modules, packs and battery systems including BMS;
- eventual potential extended use after a specified application end of life in the same application or for different second life reuse applications.

When additional tests and evaluation have been defined and done, their results may lead to:

- modifications in the testing method in agreement with the manufacturer;
- changes of the product by the manufacturer intended to obtain better results when redoing the tests when accepted by the user;
- changes of the requirements if user considers it possible.

As defined in ETSI TS 103 553-1 [1], method chart for preselection of battery products and tests for some defined applications, steps 1 to 3 can be run several times.

NOTE 6: The T_spec and T_match tables, shown as Table 3 and Table 4 respectively, are based on general applications and criteria as described in ETSI TS 103 553-1 [1] but other applications and criteria might be defined if required by the user.

Table 3: (T_Spec) Typical battery specification table defining criteria and required evaluation and complementary tests for user applications

		Application 1 (e.g. solar station)		**Application 2 (e.g. HGB)**		**Application 3 (other user defined application)**	
Criteria for battery selection (severity level included) (note 1)		**Selected criteria and their weight for the considered application**					
		x when required	**Weight (in %)**	**x when required**	**Weight (in %)**	**x when required**	**weight (in %)**
C1	IEC battery standards checklist						
C2	Energy density (Wh/kg or Wh/l) e.g. > 25 Wh/kg						
C3	Efficiency level e.g. > 80 %						
C4	High power discharge rate capability e.g. ≤ 1 h						
C5	Medium power discharge rate capability e.g. 3 to 20 h						
C6	Low power discharge rate capability e.g. 100 h						
C7	life time at defined temperature e.g. > 7 years at 35 °C with EoL capacity > 70 %						
C8	Cycling performance at defined conditions e.g. > 4 000 cycles at 50 % DoD, 35 °C and EoL capacity > 70 %						
C9	Ability to start a Genset at defined conditions e.g. 0 to 40 °C, load voltage/current profile						
C10	Partial charge acceptance e.g. no lifetime and SoH degradation without full charge at each cycle						
C11	Self-discharge (before commissioning and in service) e.g. < 10 % per month at 40 °C						
C12	Stress tolerance (defined behaviour in case of overcharge, over discharge, short circuit, etc.)						
C13	Operation with BMS off or no BMS for a defined period or a number of cycle e.g. < 100 h or < 10 cycles						
C14	Easy maintenance (note 2) e.g. no water refill, easy module or cell replacement, etc.						
C15	No derating power output up to temperature level e.g. 45 °C						
C16	Ability of regeneration procedure (note 3)						
C17	Environmental aspects						
C18	CAPEX/TCO						
	Total weight		**100 %**		**100 %**		**100 %**

NOTE 1: Criteria in this table are given as common example but they have to be fully adapted to user and application specification.

NOTE 2: Easy maintenance can be obtained by module replacement. Other solution such as cell or block replacement avoids a costly complex module replacement especially at beginning of lifetime of the battery depending on battery technology (e.g. in the case of lead-acid or nickel based technology).

NOTE 3: Regeneration applies only on some technology e.g. nickel based that can recover capacity when reduced due to memory effects or to unbalanced cell charges. For lead-acid, equalization mode consists in a small overcharge at relatively high voltage (e.g. 2,4 V) following a slow charge at limited current of C/10 followed. This may be required after a defined number of cycles without enough time to fully recharge.

Table 4: Matching table (T_match) for preselection of battery technology/product for a defined application

Considered application (e.g. solar station)		Battery preselection results Evaluation information (E) or Tests(T) (see note) or both (E+T)									
Selection criteria (severity level included)		Battery technology /Product 1			Battery technology /Product 2			Battery technology /Product 3			Comment
	weight	result	Ok or further E or T or E+T	If ok score= weight else 0	result	Ok or further E or T or E+T	If ok score = weight else 0	result	Ok or further E or T or E+T	If ok score = weight else 0	
C1											
C2											
C3											
C4											
C5											
C6											
C7											
C8											
C9											
C10											
C11											
C12											
C13											
C14											
C15											
C16											
C17											
C18											
Total score	**100 %**			**X %**			**Y %**			**Z %**	
NOTE:	Test would be done as much as possible in the defined evaluation time (e.g. 6 month self-discharge). It can be an ageing trend (loss of capacity in cycling, or at high temperature). Confidence would be higher on mature technologies. As tests may be long, in general they can be done in parallel on several battery samples.										

7 Laboratory evaluation and tests for cells and battery modules or packs

7.1 Initial considerations

For each test described in the following clauses, there should be a description of the initial condition, the laboratory test procedure and result reporting as defined in ISO/IEC 17025 [i.5].

The complementary evaluation of a battery technology proposed in the present document can be applied when evaluating the following battery types:

- Lithium iron phosphate (LFP) family with possible chemistry differences due to additives such as yttrium or manganese.
- Other clearly identified lithium chemical families (e.g. with cobalt, manganese, nickel, aluminium).
- NiZn, NiMH families with different additives.

NOTE 1: For lead-acid or NiCd, compliance to existing standards relative to a battery may be considered as this technology is sufficiently developed with long term experience and maturity and only a limited test would be required in general.

NOTE 2: For hot battery or metal-air technology as listed in clause 7.1, thermal tests or air pollution tests are very specific and would need further research before specification.

NOTE 3: More details on technology are given in Annex G. There is no test defined on the chemical content of the battery cells.

7.2 Initial checking (mechanical state, marking, interconnection quality)

Mechanical state

The battery pack surface should be clean, with no distortion or mechanical damage and no corrosion (rust, salt crystals, leakage, etc.) at the electrical contact interfaces and close to valves for pressure release or at the level of plastic solders; The jar shall not suffer from deformation due to internal pressure and high temperature which can be observed through the cycling tests.

Marking

The considered cell, battery module or pack shall have clear marking on pack surface labels or plastic engraving for:

- nominal voltage of considered cell, module or pack;
- positive and negative terminals marked with proximity clear symbols + and -.

Additional clear indications should be given for:

- voltage ranges as required if under or overvoltage affects the safety and lifetime;
- rated capacity at defined discharge rate e.g. C_1, C_3, C_5, C_{10}, C_{24}, C_{120};
- on/off switch or protective device if any;
- LEDs if any;
- command buttons if any;
- pipe connection of gas exhaust if any.

NOTE: Clear marking means clear reading helped with contrasted colour of text and background and sufficient characters size to be read at a distance of 1 metre. They should be solvent and abrasion resistant.

Interconnections

External power terminal connection shall be only of the following type:

- screw type for capacity higher or equal to 30 Ah or current > 10 A;
- screw type or fasten for capacity lower than 30 Ah.

Control/monitoring interface connection:

- For control/ monitoring interconnection and interface should comply with ETSI ES 202 336-11 [2].

7.3 Typical battery and voltage configurations

The battery unit voltage and current range for use in charge and discharge shall be clearly specified by the vendor in order to make tests.

Typical configurations of cell number should be defined for each of the considered technologies.

For example, in the case of LFP lithium and NiZn batteries the number of cells in series for a legacy voltage interface in major telecom/ICT is as follows:

- For 12 V block, there is in general only one acceptable number of cells.
- For -48 V, it could be a single 48 V module or several modules, packs or blocks of lower voltage in serial arrangement such as 6 V, 12 V, 16 V, 24 V.
- For up to 400 VDC, it could be several modules of 48 V nominal voltage in serial configuration or another configuration based on other modules or packs or blocks voltage.

7.4 Environmental and electrical characteristics measurement

The following electrical measurement applies at laboratory temperatures between 20 and 25 °C, unless otherwise specified.

When the battery technology uses a BMS/BMU, the target is to validate BMS/BMU accuracy but also battery behaviour by laboratory instrumentation when it is possible to make connections to the cells.

Accuracy of laboratory measurement of cell or battery modules and packs using laboratory instruments shall be as follows:

- cell voltage: ±5 mV (±10 mV is acceptable for the BMS/BMU)
- battery module/pack/system voltage ±300 mV
- current: ±1 % of maximum measured current
- temperature: ±1 °C for ambient temperature and cell temperature measured by contact (±3 °C is acceptable for the BMS/BMU)

Accuracy of integration should be as follows:

- coulombic charge and discharge ±1 % in Ah (±2 % acceptable for the BMS)
- energy of charge and discharge ±2 % in Wh

7.5 Uniformity of battery cells voltage in open circuit

7.5.0 General

The uniformity of open cell voltages in the battery module or battery pack should be checked as it reflects State of Health (SoH) and equalized State of Charge (SoC) of the battery system before other testing.

Cell voltage uniformity test should be done after more than 24 hours.

When cells terminals are not accessible in a module or packs, the BMS/BMU should be able to operate and display these values on the different terminals.

When cell voltage uniformity does not reach the requirement, the manufacturer should define a procedure to recover the correct cell state before any further testing. For example, it can be defined to make an initial charge.

7.5.1 LFP

In open-circuit voltage, when the battery is fully charged, the cell voltage difference between the maximum and minimum values should be less than 50 mV.

Gap between cell voltage minimum and average value should not exceed 1 % of average value.

7.5.2 NiZn

When the battery is in open circuit at full charge, after one hour, the voltage difference between cells should be in the range of ±10 mV.

7.6 Charge and discharge tests and results

7.6.1 Introduction

Charge and discharge shall follow known values defined by the manufacturer to obtain safe and reproducible operation.

The efficiency of charging and discharging cycle will also be calculated as it is an important performance indicator reflecting losses in the cell and risk of thermal issues.

7.6.2 Discharging capacity requirement

The discharge tests should be done at different temperatures and at different constant current discharge rates depending on the application to evaluate.

The battery system shall be in fully charged state obtained following the charging method defined by the manufacturer and agreed by the user for the application.

The battery is placed in the considered ambient temperature for at least 3 hours to get a stable temperature and then discharged at constant current.

The discharge is stopped when the battery voltage reaches the end of discharge voltage (or termination voltage) defined by the manufacturer at this temperature or the low voltage limit defined by the user for the proper operation of its application.

NOTE 1: The application low voltage limit can be higher than the end of discharge voltage of the battery. e.g. in -48 V system, it is common to define a low voltage level between of 43 V and 44 V to ensure 40,5 V minimum voltage at the equipment power interface in compliance with ETSI EN 300 132-2 [i.11].

The following list gives an example of tests and value settings for the test:

- ambient temperature of 25 °C ± 2 °C
  - discharge current defined for 1 h or 3 h discharge (I_1 or I_3);

NOTE 2: In these tests the current corresponding to n hours discharge rate is $I_n = C_n/n$

- ▪ termination voltage of 43,2 V;
- ▪ discharge capacity of the battery module should be not be less than the 100 % of the rated capacity.

NOTE 3: For Li-ion technology, the capacity of Li-ion battery is usually defined with 0,2 I_{10}. Below 10 °C temperature it may not provide 100 % rated capacity defined at higher temperature.

- ▪ ambient temperature of -10 °C ± 2 °C:
  - discharge current of defined for 1 h or 3 h discharge;
  - termination voltage of 43,2 V;
  - discharge capacity of the module should be not less than 60 % of the rated capacity.
- ▪ ambient temperature of 40 °C ± 2 °C:
  - current discharge of defined for 1 h or 3 h discharge;
  - termination voltage of 43,2 V;
  - discharge capacity of the module should be not less than 95 % of the rated capacity.

- ambient temperature of 55 °C ± 2 °C:
  - current discharge of defined for 1 h or 3 h discharge;
  - termination voltage of 43,2 V;
  - discharge capacity of the module should be not less than 90 % of the rated capacity.

7.6.3 Cumulative discharging energy requirement

The cumulative discharging energy in the whole cycle life should be no less than a defined energy under the given conditions of discharging current, DoD, temperature and EoL capacity (e.g. 70 % of initial value at a defined discharge rate). For example, 10 000 kWh cumulative discharging energy can be achievable for a 100 Ah 48 V Li-ion battery.

7.6.4 Charge/discharge tests

7.6.4.1 LFP

The recharge can be completed in following steps:

- Constant current charge up to a voltage limit.
- Constant voltage charge completion at that voltage limit for limited time or down to a low current threshold value.
- Constant voltage floating charge if acceptable for the considered battery module under test.

The battery cell charging voltage should be in the range of 3,50 V to 3,60 V.

The battery string equalizing voltage should be in the range of 56,0 V to 57,6 V (e.g. for 16 cells configuration).

Continuous charging current should be currently limited to one hour discharge current rate as declared by the manufacturer.

An example can be found in Annex E.

7.6.4.2 NiZn

The recharge can be completed in following steps:

- constant current charge up to a voltage limit constant voltage charge completion at that voltage limit for a limited time or down to a low current threshold value;
- constant voltage floating charge if acceptable for the considered battery module under test.

Battery cell charging voltage should be in the range of 1,9 V to 2 V. 48 V battery string voltage for 30 cells configuration:

- charging voltage should be in the range of 56,0 V to 57,6 V;
- if it is possible, floating charging voltage of about 53,5 V to 54,4 V.

Continuous charging current should be currently limited to one hour discharge current rate as declared by the manufacturer.

7.7 Cycling test and results

The battery should be tested at different rates of charge and discharge current at different temperatures.

There are settings to avoid undercharge and overcharge.

NOTE 1: For LFP it is observed that when end of recharge voltage is too high or end of discharge voltage is too low, it will increase the capacity of the battery, but cycling lifetime will be reduced. For water electrolyte technology it is important to maintain a correct charge efficiency avoiding consuming too much water. The calculated charge efficiency has to be followed at each cycle and the average value over several cycles as the value changes is based on slight changes in voltage, current, charge and discharge rate and time and temperature.

NOTE 2: A higher value than 100 % efficiency or too low a value can be seen on individual tests as the efficiency is very sensitive to temperature. A correct value is an average obtained over several similar cycles made in the conditions of voltage, current, charge and discharge rate and time and temperature. In the case of lead-acid it should comply with IEC 60896-21 [3] and IEC 60896-22 [4] to make a reconditioning charge at slow rate followed by a long boost charge period to fully charge all cells by slight overcharge balancing. Then the capacity is also measured at slow rate e.g. 10 h to check for the maximum available capacity compared to high rate of discharge.

NOTE 3: This does not have to be done unless clearly required by the manufacturer for other technologies under test of the present document. For lithium, it can induce too much overcharge and be worse. For nickel based technology, this can be applied essentially to balance the cells in a battery and to regenerate the nickel oxides on the positive electrode.

7.8 Back-up test

The back-up test is equivalent to a cycling test but with a long rest time at full charge level between charge and discharge.

It can be made at different temperatures and at different constant current discharge rates depending on different applications.

When in rest time, the battery shall be in fully charged state obtained following the charging method defined by the manufacturer and agreed by the user for the application.

NOTE: In the case of lead-acid or NiCd batteries, the full state of charge is maintained by floating mode but this may be not applicable for safety or shortened lifetime on other technologies.

The battery is placed in the considered ambient temperature for at least 3 hours to get a stable temperature.

The battery is then discharged at constant current over the defined period.

The discharge is stopped when the battery voltage reaches the end of discharge voltage (or termination voltage) defined by the manufacturer at this temperature or the low voltage value defined by the user for the proper operation of its application.

7.9 Self discharge or charge retention test

Self-discharge tests are more important, if the technology is known to have fast self-discharge and it may cause over discharge which reduces lifetime as it can occur during a long storage period.

In general, high temperature increases the self-discharge, so it is recommended to start with high temperature when required.

Simple tests can be done on cells at laboratory temperature or in a controlled temperature. The capacity is measured on the new cell just after a charge, then the charge is measured after some weeks or months of storage.

Another common test is the same test applied to a battery pack to take into account the electronic losses.

7.10 Stress tests, protection and alarm

7.10.1 Introduction to safety and accelerated ageing risks

Battery technologies can show very different behaviour when faults or abuse situations occur. It is important to check these risks and the efficiency of protections.

Nickel based battery risks are as follows:

- Internal and external short circuit creating overheating and possible metal melting and projection. The risk can be limited for external short circuits by a protective device close to the battery terminal and good cabling. Internally the risk is limited due to non-flammable aqueous electrolyte and electrodes and by using self-extinguishable plastics.

Overcharge creates gas electrolyse and pressure increases leading to valve opening. The risk is then easy to limit with air renewal in the room to avoid hydrogen explosions and prevent hydrogen over-production by controlling the battery charger voltage, current and time of charge at boost voltage if any.

Lithium based battery risks are:

- External short circuit leading to high current, overheating and possibly internal fire combustion above a threshold temperature depending on the technology. Ignition temperature is between 80 °C to 200 °C for organic electrolyte and electrode compositions. The primary solution is an external protection circuit. Ultimate protections also exist inside some lithium battery cells but are irreversible, such as internal electric thermal switch and electrochemical fuse-like protection.

- Internal lithium dendrites in the separator generally appear after over charge or discharge and create short circuits that increase temperature. It can then free oxygen of unstable materials for chemical reactions inside the cell which lead to ignition of lithium, additives and organic electrolyte. The risk of free oxygen is limited or lowered by BMS control and more stable chemical elements are used.

- Other internal short circuits caused by a metal piece will create the same risk which corresponds to the nail penetration test.

Some stress tests results are presented in Annex D.

7.10.2 Overcharge protection

When the lithium battery is put in the overcharge state e.g. by over voltage, the BMS (or BMU) shall detect it and the internal charging circuit shall be cut-off inside the battery system. In the case of failure of the BMS (or BMU) protection, an ultimate protection shall operate at least based on overheating of cells.

7.10.3 Over-discharge protection

When the lithium battery voltage reaches the termination voltage limit, the BMS (or BMU) should be able to disconnect the battery system.

7.10.4 Short-circuit protection

When a short-circuit happens on battery outputs, the battery circuit shall be disconnected immediately from the short circuit by an appropriate primary protective device in the battery system and the BMS/BMU shall limit and reduce circuit current to avoid the risk battery fire.

Moreover, an ultimate independent protection (e.g. thermal fuse or other) can also continue protecting the battery against fire risk in the case of failure of these primary protections.

NOTE: These redundant fast short-circuit protections are essential not only for the battery safety when the BMS/BMU becomes insufficient to protect the battery system but also for powering the electronics of the BMS/BMU itself that can be destroyed and so contribute to the short-circuit failure mode.

7.10.5 Overload protection

When battery discharge current is higher than the defined overload current limit, the battery system shall be disconnected from the load. In the case of failure of the previous protection, a second ultimate protection shall operate at least based on overheating of cells.

7.10.6 Over temperature protection

When the value of a measurement point of the cells temperature gets higher than the over temperature protection value or lower than low temperature protection value shown in Table 5, the battery pack shall be cut off from the circuit. If temperature returns the in the normal state, it should be automatically recovered.

Table 5: Temperature protection

Test	Charge protection temperature	Discharge protection temperature	Recovery temperature
Environmental temperature protection	60 °C ± 2 °C	65 °C ± 2 °C	45 °C ± 2 °C
Environmental protection	0 °C ± 2 °C	-20 °C ± 2 °C	0 °C ± 2 °C

NOTE: The temperature protection point and recovery point can also be set by the user or manufacturer. In all protection and alarm tests above, the battery pack and battery module should experience no leakage, smoke, fire or explosion.

7.11 BMS/BMU requirements

Parameters such as battery capacity, SoC, voltage, temperature, charging and discharging current, internal resistance (optional), SoH (optional) and cumulative discharging energy should be locally and remotely monitored by BMS/BMU as defined in clause 7.4.

The main parameters which should be remotely monitored are the following:

- Status of charging/discharging/test result:
  - battery system voltage and current;
  - battery string current;
  - battery module internal temperature;
  - battery system, string and module state of charge;
  - battery cells voltage (optional);
  - battery system or string capacity test result;
  - battery module or string state of health (optional);
  - cumulative discharging energy of a module or string (optional).
- Alarms including:
  - battery module, string over-current alarm;
  - battery module, string charging over voltage alarm;
  - discharging module, string low voltage or SoC alarm;
  - reverse polarity alarm;
  - module high temperature alarm;
  - system low temperature alarm;

- system, module loss of capacity alarm (optional SoH alarm);
- temperature/voltage/current sensor failure alarm;
- failure alarm (e.g. board hardware fault);
- communication failure.

The following parameters should only be set locally:

- charging methods such as intermittent charging or continuous charging;
- charging current and voltage thresholds.

Annex A (informative): Implementation examples of stationary batteries in telecom/ICT sites

Figure A.1 shows a typical big backup multistring 48 V battery of thousands of Ah on shelves. Each string is made of 24 cells of 2 V of gel types in series offering more than a thousand deep cycles of 80 % DoD. They are designed for autonomy of 3 hours or more. Lifetime can reach 12 years at 25 °C and 6 years at 35 °C with limited DoD cycling.

Figure A.1: 48 V multistring lead-acid battery in a telecom centre

Figure A.2 (left side) shows a typical two strings 48 V back-up battery in a telecom power cabinet with modular rectifiers and power distribution. Each 48 V battery string is made of four 12 V Absorbent Glass Mat (AGM) VRLA modules in series on a shelf. These are designed for medium lifetime in back-up use generally in floating mode and can ensure a limited number of cycles each year. Lifetime can reach 8 years at 25 °C and 4 years at 35 °C. With pure lead technology, the cycling life is not affected with temperature while it is affected with lead alloys with calcium, tin, antimony, etc. But these alloys can have other benefits for low charge rate operation in solar applications or mechanical resistance.

Figure A.2 (right side) also shows an example of a 48 V small battery on shelves external to a telecom power cabinet.

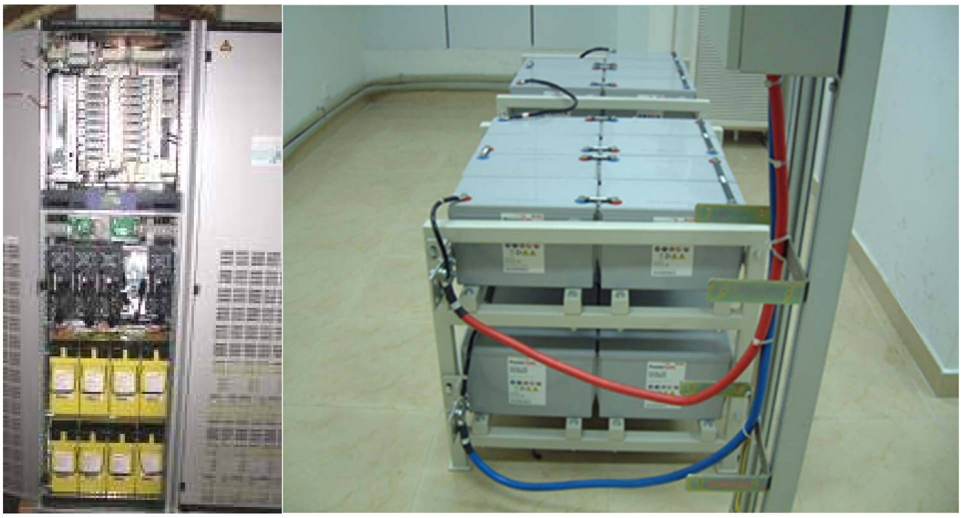


Figure A.2: Typical 48 V batteries inside or outside a telecom power cabinet

Figure A.3 shows a typical UPS high voltage multi-string back-up battery of hundreds of Ah. Each string is made of 12 V lead-acid VRLA modules in series. The design is the same as for a telecom back-up battery except that their thin plates allow high rate current enabling short autonomy of 5 to 30 minutes and few cycles.

Figure A.3: UPS multi-string batteries on shelves or in cabinets

A typical lithium 48 V battery pack or module can be used for a broad band network street cabinet or radio base station back-up.

The BMS and thermal management are integral to the pack.

Lifetime can reach 10 years at 40 °C, monitoring is natively integral, the battery can accept some thousands of deep cycles of up to 80 % DoD. 100 % cycling is possible. PSoC is not an issue on the lithium battery.

Figure A.4 shows another lithium LFP 48 V common 19" module for back-up use in a radio telecom site power cabinet e.g. in a radio base station connected on a poor electric grid adapted to hot deep cycling.

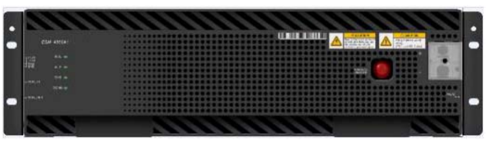


Figure A.4: Typical LFP 19" module for telecom application

Figure A.5 shows a typical solar PV system with 48 V cycling lead-acid flooded tubular battery for a telecom radio base station.

Figure A.6 shows the case of a NiCd battery that can have very long lifetime of more than 15 years with 80 % initial capacity at high temperature of 40 - 50 °C without consuming too much water, enabling water refilling only every 18 to 24 months. In comparison a tubular flooded lead acid battery requires refilling every 3 months and lasts 10 to 12 years. But the cost of NiCd is 3 to 4 times higher.

Figure A.5: Example of a solar power system for a radio mobile base station equipped with solar system equipped with flooded tubular lead-acid battery referred to as OPZS

Figure A.6: Example of a NiCd battery in an African country

Annex B (informative): SooGREEN European project

In SooGREEN paper [i.21], Figure 6 reports of the energy density classification showing the relationship between volume and weight and giving information on mechanical casing (cylindrical or prismatic type). Lithium or other pouch types are not indicated. Metal-air would probably be prismatic. NiFe, salt battery, NiZn, and hot sodium batteries.

NOTE: In the same paper, Figure 7 shows a lithium battery selection for a stationary telecom application based on safety and energy density. Figure 8 of SooGREEN shows cycling tests results of LFP cells and some effects of voltage charge and discharge voltage on capacity ageing. Ageing is reduced if wide voltage ranges (2,7 V to 3,7 V) corresponding to 100 % re-charge and maximum DoD are avoided. Working in a narrow range 3 V to 3,6 V reduces the capacity by 10 % but greatly increases the lifetime and cycling ability.

Figure B.1 shows an example of a laboratory test bank where cells and batteries measurements are done.

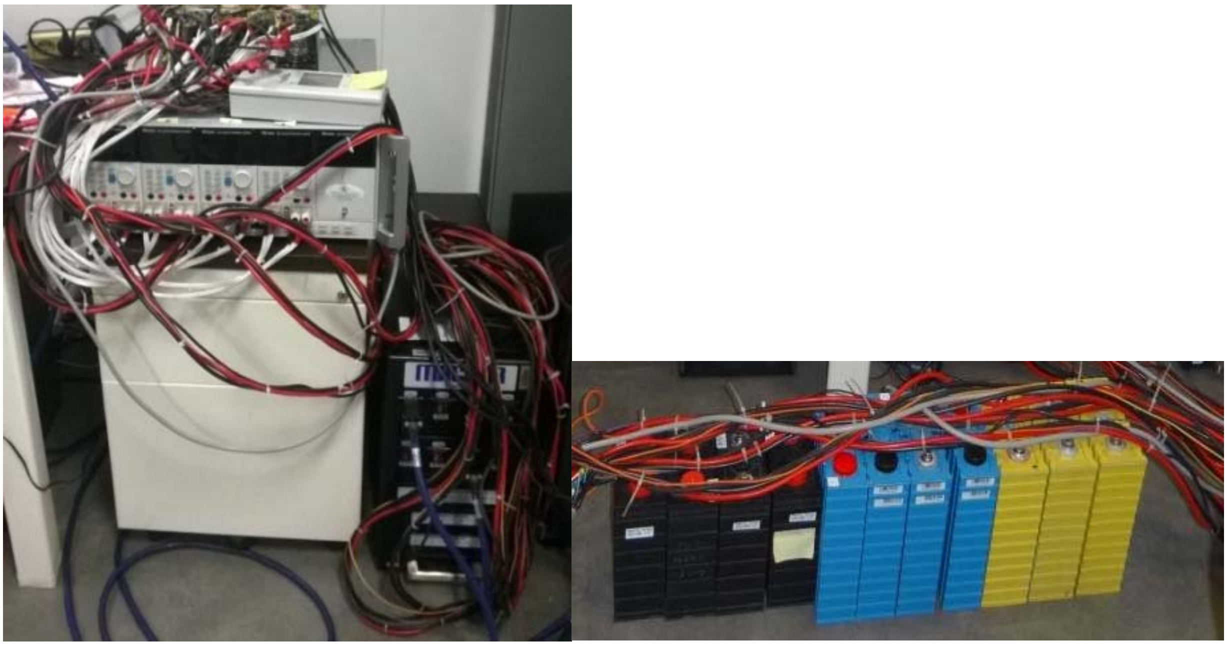


Figure B.1: Example of a test bank in a lab

Annex C (informative): Standard lithium cells commonly used in small battery modules and packs

Table C.1 shows which 3,6 V secondary lithium cells are standardized in IEC 61960-3 [i.7] and used in assembling battery modules and packs that may be used in stationary batteries.

Table C.2 gives an example of size of prismatic LFP cells.

Table C.1: Standard 3,6 V secondary lithium cells

Characteristics	1	2	3
Secondary lithium cell denomination	ICR19/66	ICP9/35/48	ICR18/68
Height (mm)	64,0/65,2	47,2/48,0	65,9/67,2
Diameter (mm)	17,8/18,5	NA	16,2/17,1
Width (mm)	NA	33,4/34,2	NA
Thickness (mm)	NA	7,6/8,8	NA
Nominal voltage (V)	3,6	3,6	3,6
End-of-discharge voltage (V)	2,50	2,50	2,50
End-of-discharge voltage (V) for endurance (cycle life)	2,75	2,75	2,75

NOTE: The end-of-discharge voltage of a battery of n series connected cells is equal to n times the end-of-discharge voltage of a single cell as listed in Table C.1.

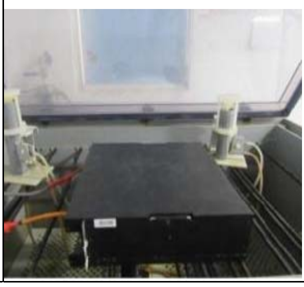
Table C.2: Standard 3,2 V LFP prismatic lithium cells

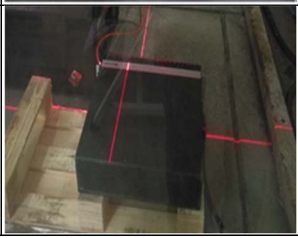
Characteristics	ESM-4850A2
Secondary lithium cell denomination	IFpP
Height (mm)	120
Diameter (mm)	NA
Width (mm)	174
Thickness (mm)	47
Nominal voltage (V)	3,20
End-of-discharge voltage (V)	2,93
End-of-discharge voltage (V) for endurance (cycle life)	2,93

Annex D (informative): Complementary information on possible stress tests and results

Table D.1 provides information on abuse or stress tests, with standard references when available, images, test procedures and passed tests conditions.

Table D.1: Information on battery stress tests

Test and information on standard	Test view example	Example of cell or battery module test procedure and passed tests conditions
short-circuit test UN38.3 [i.8]		Test procedure: EUT external casing is maintained at stabilized temperature of 55 °C ± 2 °C. The short circuit is applied on the EUT with a total external resistance of less than 0,1 ohm at 55 °C ± 2 °C and for at least one hour back at this temperature. Passed test conditions: External casing should stay at temperature lower than 170 °C and no disassembly, rupture or fire should be observed during the test and within six hours after the test.
salt spray test GB/T 2423.17 [i.9] or IEC 60068-2-11 [i.10]		Test procedure: EUT is put in a salt spray chamber maintained at 35 ± 2 °C and a salt mist of 1~2 mL/h/80 cm^2 is sprayed continuously for 72 h at this temperature. The salt mist is made of a solution of concentration of 5 ± 1 % by weight prepared by dissolving 5 ± 1 parts by weight of sodium chloride (NaCl) in 95 parts by weight of demineralized water and the PH value of the solution is between 6,5 and 7,2. Passed test conditions: The percentage of total area which shows base metal corrosion is less than 0,25 %, the diameter of the area which shows base metal corrosion is less than 3 mm.
moisture dust test		Under definition

Test and information on standard	Test view example	Example of cell or battery module test procedure and passed tests conditions
shock test UN38.3 [i.8]		Test procedure: EUT should be secured to the testing machine by means of a rigid mount supporting all its mounting surfaces. EUT is submitted to half-sine shock pulse of peak acceleration (6 ms duration at peak acceleration of 150 earth gravity (g) for small EUT and 11 ms at 50 g for large EUT. A total of 18 shocks are applied to the EUT (3 shocks in positive direction followed by 3 shocks in the negative direction of 3 mutually perpendicular mounting positions of the EUT). Voltage is tested before and after shock test so EUT should not be in fully discharged SoC for this test. Passed test conditions: No leakage, venting, disassembly, rupture or fire are observed and the open circuit voltage of EUT after testing is not less than 90 % of its voltage immediately prior to this procedure.
liquid test		Under definition
130 °C thermal shock		Test procedure: The EUT is placed in a high temperature chamber, and the temperature inside the chamber is raised to 130 °C ± 2 °C with a slope of 5 °C ± 2 °C/min and kept there for 30 min. Passed test conditions: No fire, no explosion.

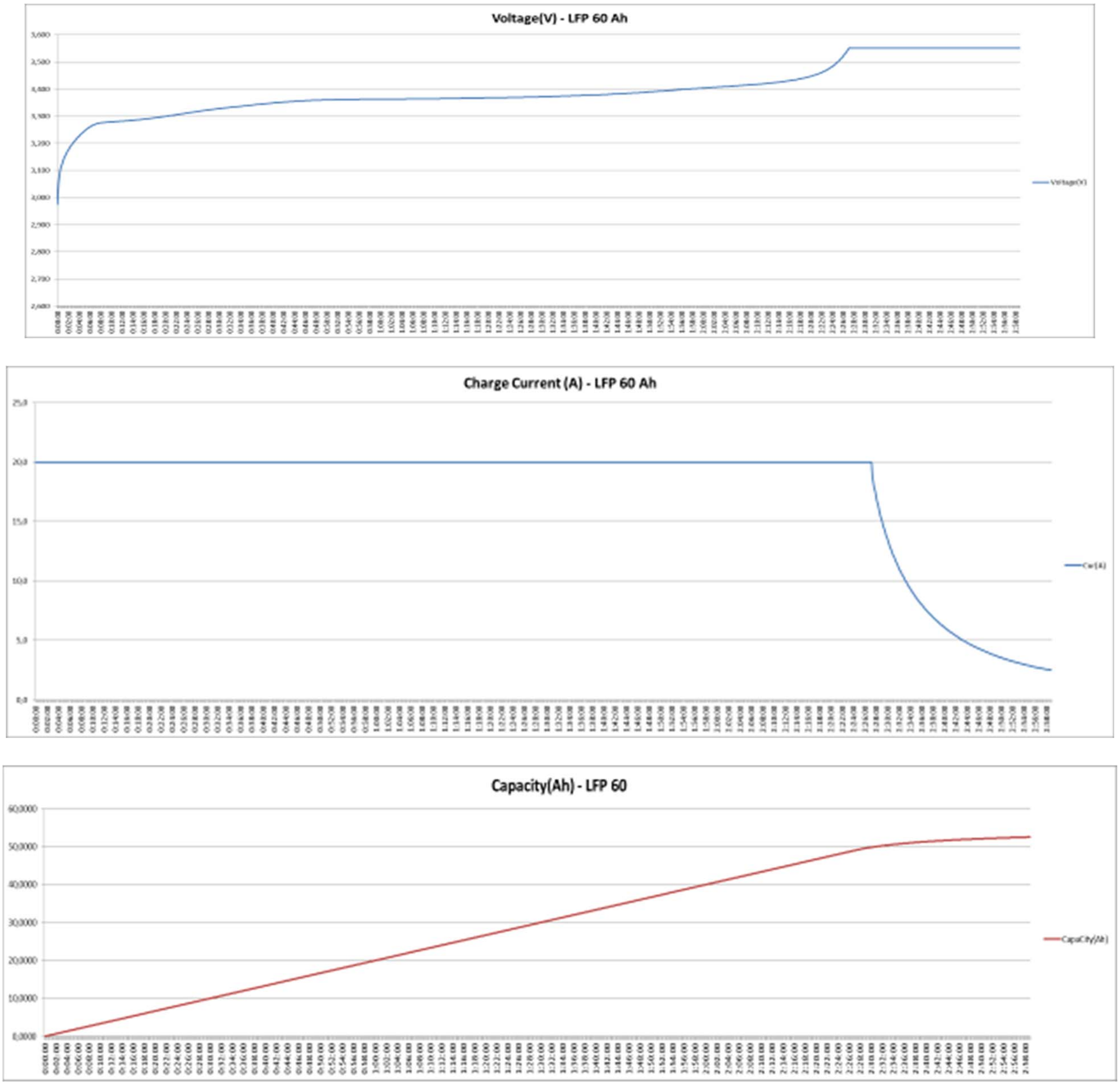
Annex E (informative): Example of charge, discharging test curve and cycling result

For LFP technology, Figure E.1 gives examples of typical constant current/constant voltage (IU mode) recharge curves of an LFP cell (part E.1a) and typical constant current charging and discharge curves of a 48 V LFP battery module (part E.1b).

NOTE 1: Constant current charge mode is called I charge and constant voltage charge mode is called U charge. When both are applied in sequence, it is called IU charge mode.

NOTE 2: Voltage can be slightly different with LFP batteries coming from manufacturers using different internal active materials in electrodes, separators and electrolytes.

a)



b)

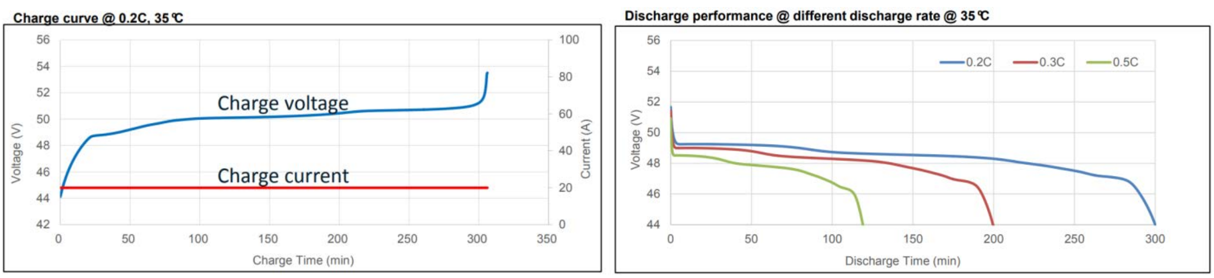


Figure E.1: a) Typical curves of constant current/constant voltage (IU mode) charge and of recharged capacity for a 60 Ah LFP cell and
b) Typical curves of constant current (I mode) at 5 h charge and 5 h discharge rate and 35 °C for a 100 Ah 48 V LFP battery module

For NiZn technology, Figure E.2 gives an example of a typical IU mode recharge curve of a NiZn cell.

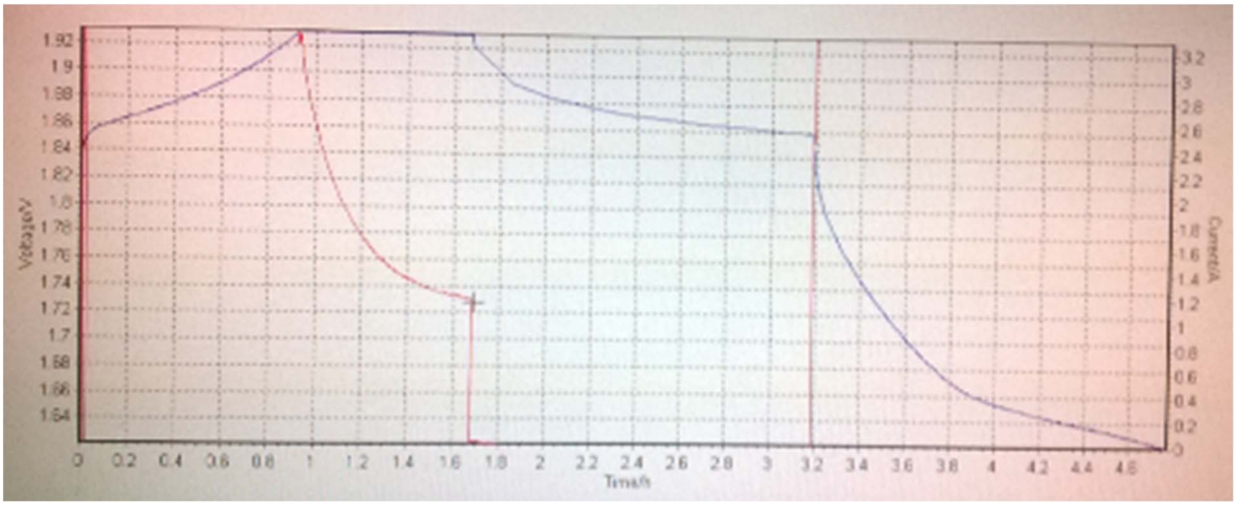


Figure E.2: Typical laboratory test result curves of charge and discharge voltage and current for a 10 Ah NiZn (voltage in red, current in blue)

The following typical cycling tests results in Figures E.3, E.4 and E.5 are presented for illustration purposes:

- Figure E.3a: a single LFP cell of nominal capacity of 90 Ah tested at 22 A charge/22 A discharge cycling period without rest time in about 8 h per cycle (3 cycles per day) in ambient temperature 25 °C - 35 °C.
- Figure E.3b: a 48 V battery module of 100 Ah.
- Figure E.4: a single NiZn of nominal capacity of 10 Ah tested at 10 A charge/10 A discharge in about a 2 hours cycling period without rest time (12 cycles per day) at cell temperature 35 °C.
- Figure E.5: a 12 V NiZn battery of nominal capacity of 10 Ah made of 8 cells in series tested at 3 A charge/5 A discharge with a short rest time for about 8 hours cycling period (3 cycles per day) at ambient temperature of 35 °C.

NOTE 3: As can be seen in the examples, there can be aberration in the result due to issues in real life laboratory tests.

NOTE 4: All values should only be considered as illustrative.

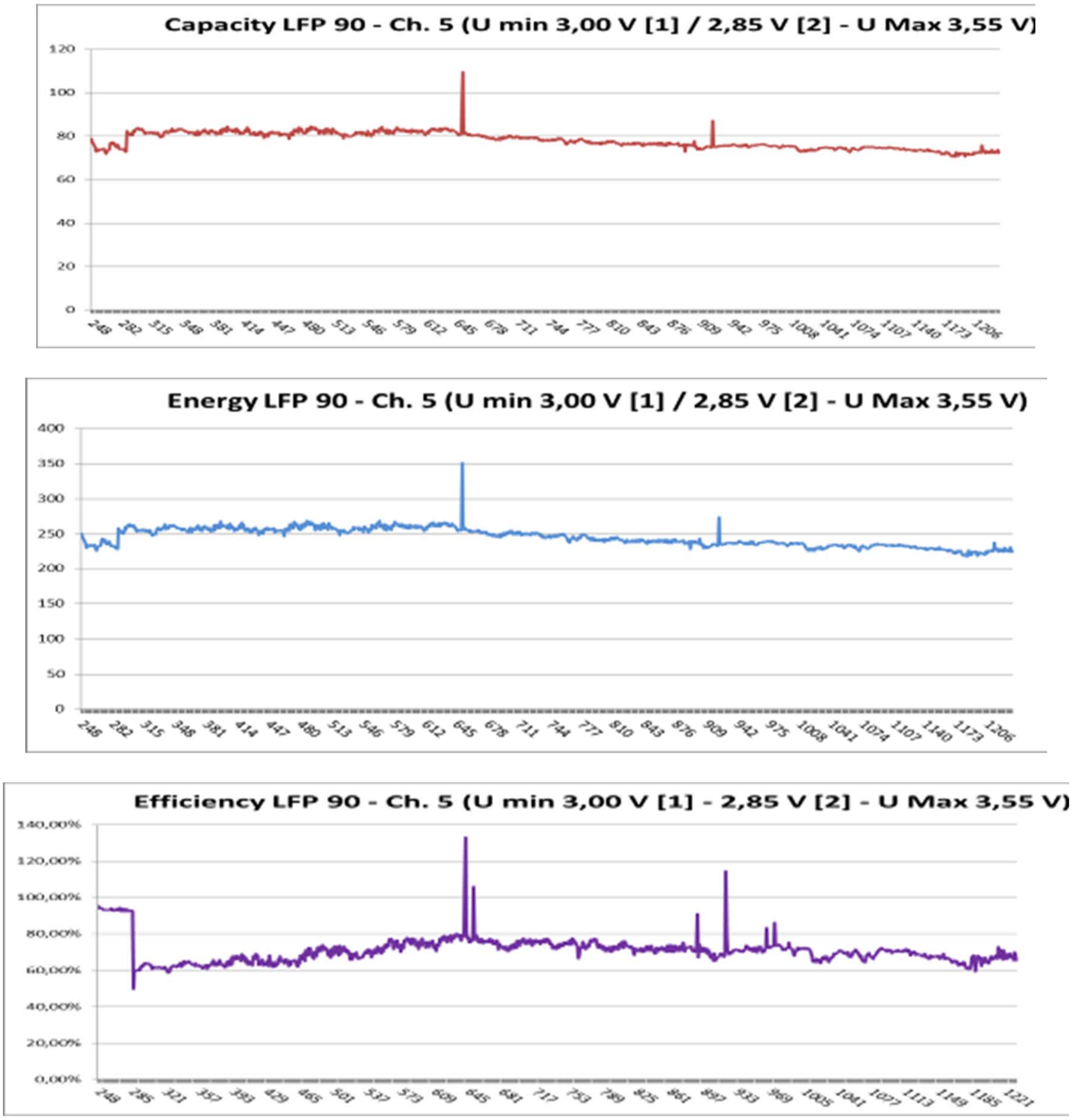


Figure E.3a: 90 Ah LFP cell cycling and efficiency test results at C/4 discharge rate, 100 % DoD at 25 °C - 35 °C

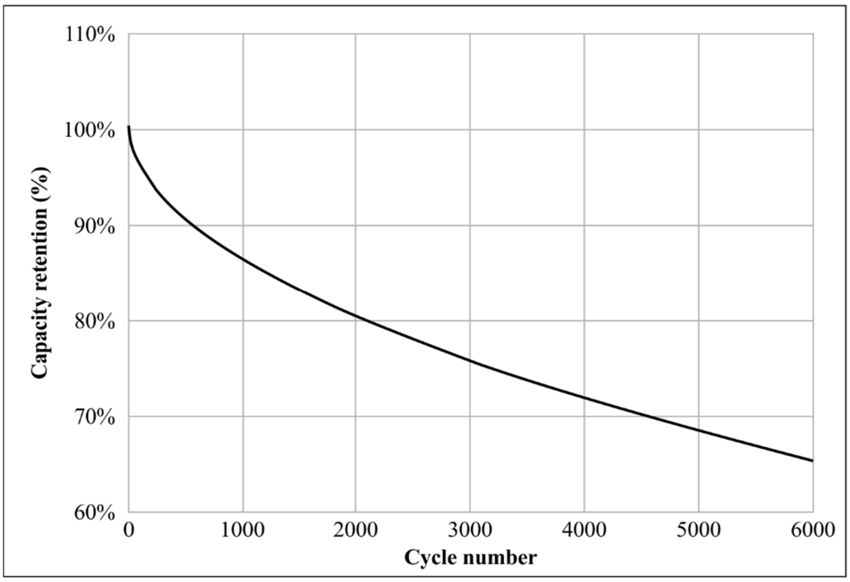


Figure E.3b: 48 V battery pack cycling test result at 35 °C, 0,5 C discharge cycles at 85 % DoD (6 000 cycles obtained at EOL capacity of 60 %)

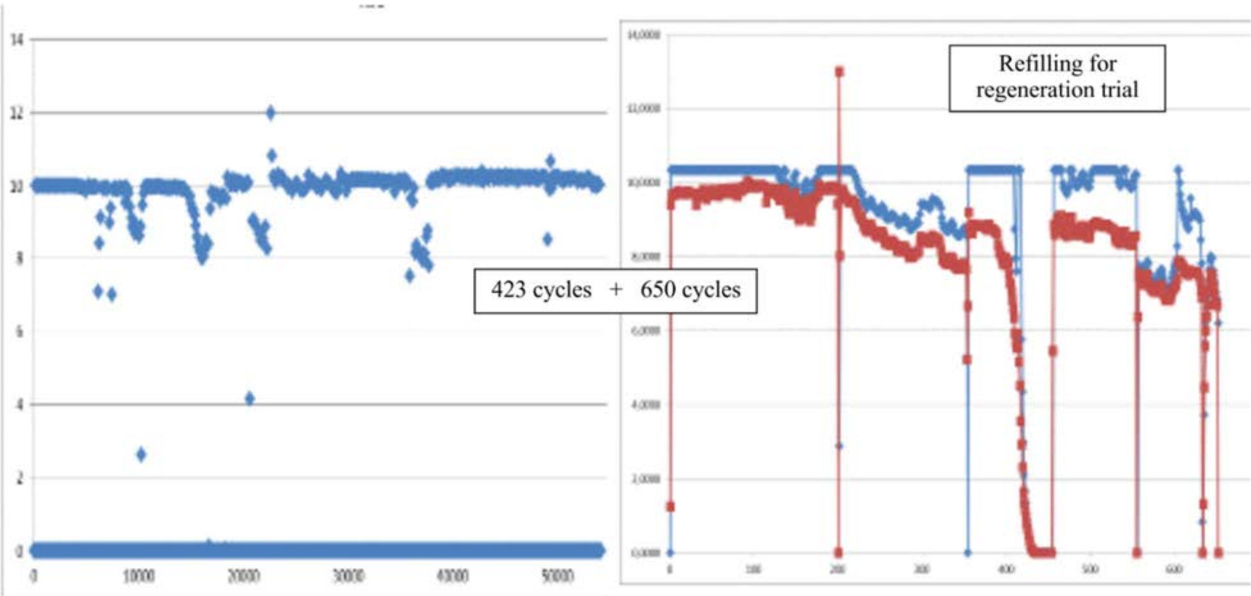


Figure E.4: 100 % DoD 1,65 V NiZn 10 Ah cell cycling test result and efficiency calculation for single at 35 °C (part 1 cycling tests in Ah versus time, part 2 in mAh versus cycle No.)

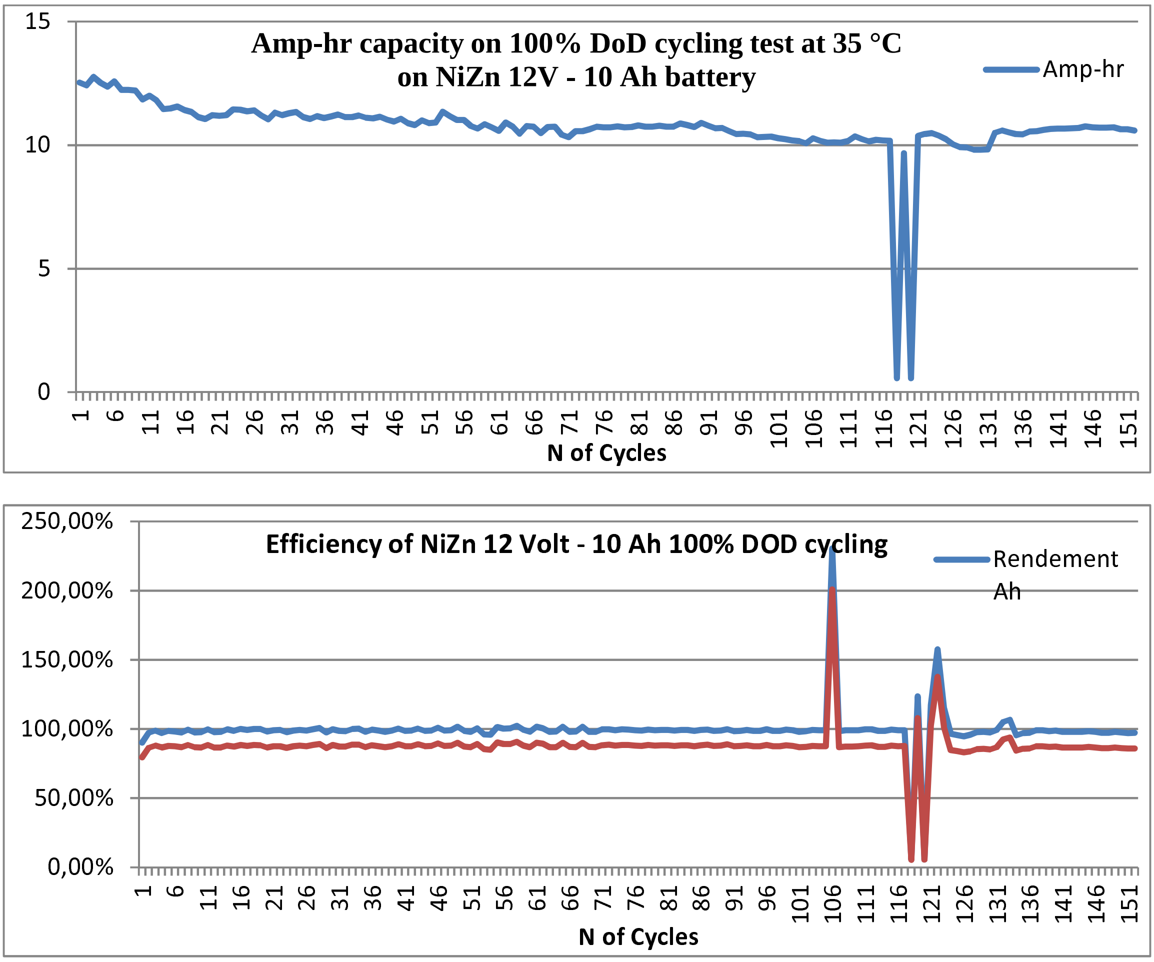


Figure E.5: 12 V NiZn 10 Ah battery cycling test results and efficiency calculation at 35 °C

Annex F (informative): Example of tables of criteria for preselection of technologies adapted to a use case and additional tests definition

This annex provides examples of completed T_Spec and T_match tables corresponding respectively to Table 3 and Table 4 defined in clause 6 for the application of Hybrid Genset Batteries (HGBs). Table F.1 presents an example of a completed specification table and Table F.2 presents an example of a matching table for preselection of battery technologies.

Table F.1: Example of battery specification table (T_Spec) defining criteria and required evaluation and complementary tests for user applications

Criteria for battery selection (severity level included)		Solar station		HGB		Pole short back-up of BS on good grid	
		Selected criteria and its weight for the considered application					
		x if required	Weight	x if required	Weight	x if required	Weight
C1	IEC battery standards checklist	x	5 %	x	5 %	x	5 %
C2	Energy density (Wh/kg or Wh/l) e.g. > 25 Wh/kg					x	10 %
C3	Efficiency level e.g. > 80 %	x	5 %	x	7,5 %		
C4	High power discharge rate capability e.g. ≤ 1 h					x	5 %
C5	Medium power discharge rate capability e.g. 3 to 20 h	x	5 %	x	5 %		
C6	Low power discharge rate capability e.g. 100 h	x	5 %				
C7	Calendar life at defined temperature e.g. > 7 years at 35 °C with EoL capacity > 70 %	x	10 %	x	5 %	x	30 %
C8	Cycling performance at defined conditions e.g. > 4 000 cycles at 50 % DoD, 35 °C and EoL capacity > 70 %	x	20 %	x	20 %		
C9	Ability to start a Genset at defined conditions e.g. 0 to 40 °C, load voltage/current profile			x	5 %		
C10	Partial charge acceptance e.g. no lifetime and SoH degradation without full charge at each cycle	x	5 %	x	7,5 %		
C11	Self-discharge (before commissioning and in service) e.g. < 10 % per month at 40 °C	x	5 %	x	5 %	x	5 %
C12	Stress tolerance (defined behaviour in case of overcharge, over discharge, short circuit, etc.)	x	5 %	x	5 %	x	5 %
C13	Operation with BMS off or no BMS for a defined period or a number of cycle e.g. < 100 h or < 10 cycles					x	5 %
C14	Easy maintenance (note 2) e.g. no water refill, easy module or cell replacement, etc.	x	5 %	x	5 %	x	5 %
C15	No derating power output up to temperature level e.g. 45 °C			x	5 %	x	5 %

Criteria for battery selection (severity level included)		Solar station		HGB		Pole short back-up of BS on good grid	
		Selected criteria and its weight for the considered application					
		x if required	**Weight**	**x if required**	**Weight**	**x if required**	**Weight**
C16	Ability of regeneration procedure (note 3)	x	5 %				
C17	Environmental aspects	x	10 %	x	10 %	x	10 %
C18	TCO < 300 €/kWh on 15 years	x	15 %	x	15 %		15 %
	Total weight		**100 %**		**100 %**		**100 %**

NOTE 1: Test would be done as much as possible in the defined evaluation time (e.g. 6 month self-discharge). It can be ageing trend (loss of capacity in cycling, or at high temperature). Confidence would be higher on mature technologies. As tests may be long, in general they can be done in parallel on several battery samples.

NOTE 2: Easy maintenance can be obtained by module replacement. Other solutions such as cell or block replacement avoids a costly complex module replacement especially at beginning of lifetime of the battery depending on battery technology (e.g. in the case of lead-acid or nickel based technology).

NOTE 3: Regeneration applies only on some technology e.g. nickel based that can recover capacity when reduced due to memory effects or to unbalanced cell charges. For lead-acid, equalization mode consists in a small overcharge at relatively high voltage (e.g. 2,4 V) following a slow charge at limited current of C/10 followed. This may be required after a defined number of cycles without enough time to fully recharge.

Table F.2: Matching table (T_match) for preselection of battery products or technology for an application and for deciding and defining of required complementary evaluations and tests

Considered use case: Solar station		Considered technologies in the preselection step					Preselection result and additional evaluations or test requirements
Relevant criteria for battery system selection	**Requirement level: Evaluation (E) Tests (T)**	**OPZV S and V lead acid**	**NiCd**	**LFP**	**Other Li**	**NiZn**	
Energy storage specific standards checklist (note 1)	E	IEC 60896-11 [i.24] IEC 61427-1 [i.25] IEC 60896-21 [3] and 22 [4] EUROBAT 2015 [i.26] IEC 62485-2 [i.27]	IEC 62259 [i.28] IEC 61434 [i.29] IEC 60623 [i.30]	IEC 62619 [i.6] IEC 62620 [i.18]	IEC 62619 [i.6] IEC 62620 [i.18]	IEC 61434 [i.29]	Ok for lead and NiCd need complementary tests for others
Energy density Wh/kg		30	40	60 (note 2)	50 (LTO) other > 100	70, need tests	known but not essential
Energy efficiency > 70 %	T	> 75 %	> 70 %	> 85 %	need tests	> 80 %	can be ok
High power (≤ C1)							
Medium power (C3 - C20)	T (recharge)	ok	ok	need test for solar cycling	need test for solar cycling	ok	need more tests if lithium
Low power (> C20)	T (discharge)	ok	ok	ok	ok	ok	ok
Calendar life at defined temperature	E+T	ok depending on water refilling	better with less refilling	No water need tests to confirm	No water need tests to confirm	few water refill, need test	issue is length of calendar life tests
Cycles at defined temperature	E+T	ok if oversized for low 15 - 25 % DoD	slightly better than lead, no test required	ok at 50 - 85 % DoD	LTO is the best	need test at 50 - 70 % DoD	need accelerated tests when possible
Starting power at defined temperature							
Partial charge acceptance	E+T	very limited	yes	yes	yes	yes	ok except lead
Self-discharge (before commissioning)	T	can be an issue	no issue	can be an issue of locked BMS	can be an issue of locked BMS	no issue	need more tests for lithium

Considered use case: Solar station		**Considered technologies in the preselection step**					**Preselection result and additional evaluations or test requirements**
Relevant criteria for battery system selection	**Requirement level: Evaluation (E) Tests (T)**	**OPZV S and V lead acid**	**NiCd**	**LFP**	**Other Li**	**NiZn**	
Abuse tolerance (overcharge, discharge no water refill, etc.)	T	limited	high	low	low	medium	need more tests for lithium
Operation with BMS off	E+T	no BMS	no BMS	small acceptance	no acceptance	no issue	need more tests for Lithium
Easy maintenance	E+T	ok	ok	possible	no, except LTO	ok	need more tests for LFP
Regeneration procedure	T	small	electrolyte replacement	no	no	possible, need tests	need more tests for NiZn
CAPEX/TCO	E	good	medium	medium	need investigate	need investigate	need more information
NOTE 1: For example ISO 9001 or ISO 14001 may be requested as for many other equipment items but are not specific to battery. NOTE 2: To have a robust (mechanical shape) the lithium battery density is much lower than cell density.							

Annex G (informative): Technology and chemistry identification

The chemical composition of metallic blends in cathodes and anodes is an essential indicator for choosing a lithium battery adapted to use and there are more and more solutions.

This is less obvious for other technologies (NiMH, NiZn) that always use the same main components and only additives not clearly indicated in the battery name influence properties such as for example in the case of lead-acid (e.g. batteries with pure lead or with added calcium have low self-discharge and good recombination, antimony helps for cycling and mechanical resistance, etc.).

Lithium battery cathode

The following lists give the common chemical compositions of cathode active materials (positive electrodes) and their main characteristics:

LCO: Lithium Cobalt Oxide

- Older technology (consumer batteries)
- Good energy density
- Poor safety/ thermal properties

LMO: Lithium Manganese Oxide

- Current technology
- Good safety/thermal properties
- No expensive cobalt
- Low energy density

LFP: Lithium Iron Phosphate

- Current technology
- Good safety/thermal properties
- No expensive cobalt

NCM blend of three lithium oxides: Nickel/Cobalt/Manganese

- Current technology
- Good energy density
- Moderate safety (not as stable as LFP)
- No expensive cobalt
- Lower energy density
- Less cobalt gives lower cost, better safety/thermal properties, medium performance
- More nickel increases energy density
- More manganese gives potentially much higher energy density and lower cost but needs better electrolytes and anode

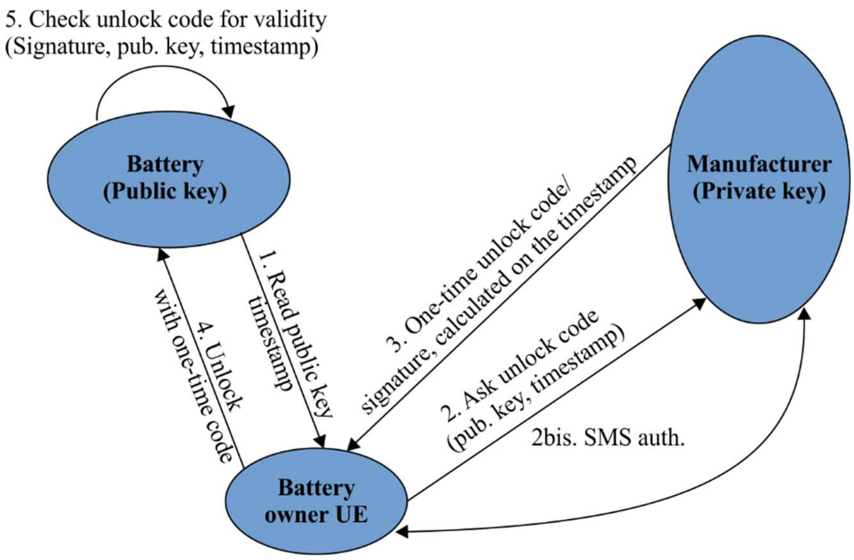
Lithium battery anode

There are also possible disruptive evolutions of the negative electrode (anode) from carbon to silicon, as silicon theoretically absorbs 10 times as many Li ions as graphite, allowing a much higher energy density. But the silicon structures suffer from fatigue/pulverisation after a few cycles due to an approximate quadruple change in volume due to the insertion mechanism. Nanostructures/nanowires could to some extent solve this and small volumes on small cells are becoming commercially available.

As can be seen in these few examples in battery evolution, when mature technology with long term field experience is required, it is essential to know enough about the internal chemistry of the cell.

Annex H (informative): Public key infrastructure

The use of public key infrastructure, for unlocking recovered stolen batteries by the owner, could be developed as shown in Figure H.1.



NOTE 1: Read public key could be done using passive NFC tags on the batteries and NFV compatible battery owner UEs. Although not a panacea for security, use on NFC is OK here since it is to read a public key and these within a confined environment (e.g. ICT cabinet).

NOTE 2: Timestamp should use a 64 bit value in order to avoid the trap of "year 2038" bug tied to the 32-bit time values in legacy systems.

NOTE 3: The unlock interface between the owners US and battery is to be agreed upon between owner (typically MNO) and battery manufacturer; without a better agreement upon solution, use of NFC is suggested by default.

NOTE 4: Cryptographic primitives to use are out of scope for the present document. Nevertheless following trends in PQ crypto standardization is recommended.

Figure H.1: Example of public key infrastructure, for unlocking recovered stolen batteries

History

Document history		
V1.1.1	November 2021	Publication