



TECHNICAL SPECIFICATION

**Environmental Engineering (EE);
Innovative energy storage technology for stationary use;
Part 1: Overview**

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Foreword

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

The present document introduces an open series of documents for different families of technologies (battery systems, super-capacitors systems) that will be enriched progressively as new technologies emerge that may significantly impact the field of energy storage.

With the increase of new technologies in energy storage there is need for a global overview of an energy storage system for use in stationary information and communication technology (ICT) installations in networks, data centres and customer premises equipment (CPE), and simple evaluation of acceptable duration and characterization methods for this specific purpose.

The present document is part 1 of a multi-part deliverable covering "Innovative energy storage technology for stationary use", as identified below:

- Part 1: "Overview";
- Part 2: "Battery technology";
- Part 3: "Super-capacitor technology".

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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Introduction

Until early 2000, the battery technology has been dominated by Lead-acid for stationary uses and motive uses (factory fork lifts, engine starters). NiMH and Lithium have been used for mobile devices, portables tools and partially for electric vehicles. There have also been used for highly reliable and secure applications in fields such as industry, transport, etc.

The recent and relatively fast evolution of batteries, in particular lithium-ion has been driven by the rapid development of electric cars for urban use in fleets and more recently for popular commuter use in vehicle for public and private transport. The latest battery research has been directed toward technology enhancements that support an increase in distance travelled by vehicle using a single charge and a reduction in the time taken to re-charge the battery. Vehicle battery technology is rapidly expanding to include other battery technology areas offering product advantage in terms of reduced cost, safer usage, higher energy density levels and quicker charging. These include solid state batteries, aluminium ion, lithium sulphur and metal air. These strong developments of battery technologies can be applied in stationary Information and Communication Technology (ICT) industry.

An energy storage and generation technology that appears to move in and out of the battery lime light is the fuel cell. This technology comes in various different assortments but is best known as the hydrogen fuel cell for which a very high power density at 0,7 Watt per cm² or higher is possible, depending on operating conditions. Car manufacturers are considering extending batteries range with general optimizing in hybrid solutions with fuel cell, or internal and external engine generators. Fuel cell technology remains a potential contender for future use by electric vehicle manufacturers. Fuel cells have also been used in several ICT site trials and installations by major telecom providers.

The European Union (EU) Renewable Energy Directive [i.24] states that the EU is to meet at least 20 % of its total energy needs with renewable energy by 2020 through individual national targets of its member states. In revision work of the directive, the EU indicates new target of at least 27 % Renewable Energy of its final consumption by 2030.

Depending on the energy mix, the existing electric grid can accept in average injection of up to 10 % to 30 %, of renewable energy by only adding regional big energy storages for example water Pump Hydro Storage (PHS) or Compressed Air Energy Storage (CAES) connected to the high voltage grid. Above this level of intermittent renewable energy in some places or more generally in regions or countries, there is a need for smaller local storages in general made of electro-chemical batteries. Statistical analysis carried out within the EU in 2014 showed that 25,4 % of its total primary energy production came from renewables. This was made up of 16 % biofuels, 4,2 % hydropower, 2,83 % wind and 1,55 % solar. These technologies were further augmented with large regional energy storage solutions such as PSH and CAES, both solutions offering peak time energy stability to the high voltage grid. Although the EU can boast of having very high levels of renewable energy solutions, there is a need to further support these solutions in some regions where large renewable energies are still in development or offer intermittent or limited energy supply. This point is particularly true in some countries outside of the EU borders where there is a need for smaller local storages solutions. In general these solutions comprise of electro-chemical batteries.

In attempts to make the ICT sites more autonomous or interactive with the local utilities e.g. by peak shaving, demand response, etc., local battery installations are offering 'self-consumption' of renewable energy. This is achieved by charging local battery stacks using solar technology and as such providing site power at night and in periods of bad weather. In these particular examples there is a need to move away from pure back-up use of battery often in charge floating mode to charge/discharge cyclic use and in addition where site power requirements dictate, short term storage solutions such as super- capacitors should be considered.

With the development of sectors such as Internet of Things (IoT) and Machine to Machine (M2M) technologies, uninterrupted stationary power supplies have become more and more important where energy consumption is too high for using primary batteries due to size, cost and frequency of replacement. Therefore, rechargeable batteries are necessary for resilience and energy harvesting.

Further information on all these subjects can be found in various studies on energy storage such as the IEC White paper [i.9] or other presentations and publications e.g. in [i.13], [i.14], [i.15], [i.16], [i.17] and [i.19].

The trend towards the use of more cyclic battery technologies and super capacitors can be observed on international battery market evolution presented in annex A.

To this end to facilitate the choice of adapted storage solutions for stationary use in the ICT sector, simple and effective methods are developed in this multi part deliverable. They should give results in reasonable time which is introduced in the present document "ETSI TS 103 553-1: Overview".

Detailed information and methods are given in next parts for each family of technologies:

- ETSI TS 103 553-2 battery technology [i.25];
- ETSI TS 103 553-3: super-capacitors technology [i.26].

Future possible parts could be other storage technologies (e.g. fuel cells, mechanical storage).

With an increase in the selection of different manufacturers offering energy storage systems with different battery and super-capacitor technologies it has become increasingly difficult for the designer and the user to make the correct selection for their end system.

The intention of these evaluation methods is not to substitute but to complement the IEC standards on batteries for safety or factory tests such as [i.12] for Stationary lead-acid batteries or [i.10] and [i.11] for alkaline batteries or other non-acid electrolytes batteries or any new IEC standard on new energy storage technologies e.g. batteries, fly-wheel, etc.

The present document was developed jointly by ETSI TC EE and ITU-T Study Group 5 and published respectively by ITU and ETSI as Recommendation ITU-T L.1220 [i.27] and ETSI TS 103 553-1 (the present document), which are technically equivalent.

1 Scope

The present document identifies the main needs and applications of stationary electrical energy storage for ICT sites such as back-up on different grid quality and cyclic use of renewable energy systems. It also provides possible selection criteria for the correct choice for the end system. The topics considered are:

- families of electrical energy storage such as batteries or super-capacitors;
- technologies types and their main properties;
- adaptation to requirements (functionalities, technology availability, electrical characteristics, environmental adaptation, maintenance type, cost, etc.);
- national or regional rules and regulations.

The present document highlights the need of evaluation methods that are complementary to existing battery standards as they allow different time frame including shorter tests compared to common energy storage industry tests.

The present document introduces a series of subparts that covers energy storage technologies (battery, super-capacitor, etc.) applicable to stationary Telecom/ICT equipment used in telecom networks, data centres and customer premises (CPE).

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 EN 300 132-2: "Environmental Engineering (EE); Power supply interface at the input of Information and Communication Technology (ICT) equipment; Part 2: -48 V Direct Current (DC)".
- [2] Recommendation ITU-T L.1001 (11/2012): "External universal power adapter solutions for stationary information and communication technology devices".

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.1205 (12/2016): "Interfacing of renewable energy or distributed power sources to up to 400 VDC power feeding systems".

- [i.2] ETSI EN 300 132-3-1 (V2.1.1): "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".
- NOTE: An ongoing work should result in ETSI EN 300 132-3 replacing ETSI EN 300 132-3-1.
- [i.3] ETSI EN 302 099 (V2.1.1): "Environmental Engineering (EE); Powering of equipment in access network".
- NOTE: Annex C refers to ongoing revision work.
- [i.4] ETSI TR 102 532 (V1.1.1) (2009-06): "Environmental Engineering (EE) The use of alternative energy sources in telecommunication installations".
- [i.5] RSE (Ricerca Sistema Energetico) report (2011): "L'accumulo di energia elettrica".
- [i.6] CEER (Council of European Energy Regulators) (2015-02): "Benchmarking Report 5.2 on the Continuity of Electricity Supply".
- NOTE: Available at <https://www.ceer.eu/documents/104400/-/-/cbc48e6a-5d5e-a170-ae1d-7b7b298d46a4>.
- [i.7] AEEGSI Report (2015-05).
- NOTE: Available at: https://www.autorita.energia.it/allegati/com_stampa/15/151116cs.pdf.
- [i.8] IEC 60050-826 (2004): "International Electrotechnical Vocabulary - Part 826: Electrical installations".
- [i.9] IEC WPstorage: "IEC Energy storage White paper".
- NOTE: Available at <http://www.iec.ch/whitepaper/pdf/iecWP-energystorage-LR-en.pdf>.
- [i.10] IEC 62619 (2017-02): "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.11] IEC 62620 (2014-11): "Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for use in industrial applications".
- [i.12] IEC 60 896 series: "Stationary lead-acid batteries".
- [i.13] IRES and ESE 2016-T&E (2016-03): "International IRES and European ESE Conference".
- NOTE: Available at <https://eurosolar.de/en/index.php/text-and-media/press-releases-eurosolar>.
- [i.14] ETSI EE 2015-Storage Solutions (2015-06): "Energy Storage Solutions Panorama for Telecom Stand-By applications", Campion 3Cprojects, Third ETSI Workshop on ICT Energy Efficiency and Environmental Sustainability, Sophia Antipolis.
- NOTE: Available at https://docbox.etsi.org/Workshop/2015/201506_EEWORKSHOP.
- [i.15] Elsevier 2016-ESS applications (2016-08): "Energy storage technologies and real life applications - A state of the art review".
- [i.16] Battery University website.
- NOTE: Available at http://batteryuniversity.com/learn/article/types_of_lithium_ion.
- [i.17] ENEA Fact & Figures (2012-03): "Issues, Technical solutions and development opportunities".
- NOTE: Available at <http://www.enea-consulting.com/wp-content/uploads/2015/05/ENEA-Consulting-Energy-Storage.pdf>.

- [i.18] ESA (Energy Storage Systems) (2007-01): "Characteristics and Comparisons". Wind Energy Research Laboratory (WERL), Université du Québec Canada.
- NOTE: Available at https://www.researchgate.net/publication/223915340_Energy_storage_systems-Characteristics_and_comparisons.
- [i.19] SooGREEN: The 2017 International Workshop on "Service-oriented Optimization of Green Mobile Networks".
- NOTE: Available at <http://dl.ifip.org/db/conf/wiopt/wiopt2017/1570349026.pdf>.
- [i.20] European Commission Smart Grid Mandate (source of definition in M490): "Standardization Mandate to European Standardisation Organisations (ESOs) to support European Smart Grid deployment".
- NOTE: Available at <ftp://ftp.cencenelec.eu/CENELEC/Smartgrid/M490.pdf>.
- [i.21] Source of definitions in IADC UBO / MPD Glossary, December 2011. Global Standards <http://www.iadclexicon.org/load-shifting/> and in <http://www.iadclexicon.org/peak-shaving/>.
- [i.22] Source of definition in <https://cdn.eurelectric.org/media/1940/demand-response-brochure-11-05-final-lr-2015-2501-0002-01-e-h-C783EC17.pdf>.
- [i.23] Avicenne Energy (2017-02): "Evolution du marché mondial des batteries rechargeables, Impact sur la demande en Nickel, Cobalt et Lithium".
- NOTE: Available at http://www.mineralinfo.fr/sites/default/files/upload/comes_presentation-c_pilot_fevrier_2017_pour_diffusion.pdf.
- [i.24] The European Union (EU) Renewable Energy Directive.
- NOTE: Available at <https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive>.
- [i.25] ETSI TS 103 553-2: "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 2: battery technology".
- [i.26] ETSI TS 103 553-3: "Environmental Engineering (EE); Innovative energy storage technology for stationary use; Part 3: super-capacitor technology".
- [i.27] Recommendation ITU-T L.1220 (08/2017): "Innovative energy storage technology for stationary use, Part 1: Overview of energy storage".
- [i.28] Recommendation ITU-T L.1200 (05/2012): "Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment".

3 Definition of terms, symbols and abbreviations

3.1 Terms

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

-48 VDC: -48 Volt Direct Current voltage range

NOTE: As standardized in Recommendation ITU-T L.1200 [i.28].

400 VDC: up to 400 Volt Direct Current voltage range

NOTE: As standardized in ETSI EN 300 132-3-1 [i.2].

back-up energy storage: energy storage system able to feed electricity to equipment of an ICT site in case of electric grid or local source unavailability or insufficiency of power source (electric grid or local source) to match the load demand

demand response: utility demand to final consumers (households or businesses) providing response in manual or automatic mode giving flexibility to the electricity system by voluntarily changing their electricity consumption in reaction to price signals or to specific requests which lead to lower prices for consumers and for utility by avoiding grid over-load and decreasing the need of high-cost power generation often using fossil energy and emitting carbon emission

electrical equipment: item used for purposes like storage, generation, conversion, distribution or utilization of electric energy (e.g. electrical machines, transformers, switch gear and control gear, measuring instruments, wiring systems, current-using equipment, etc.)

NOTE: As standardized in IEC 60050-826 [i.8].

energy storage: action or mean to store energy for use in the future

lithium based battery: battery that uses Lithium in electrode

load shifting: moving an entire load from a peak time to an off-peak time

NOTE: As standardized in IADC UBO/MPD Glossary [i.21].

nano grid, micro grid: local area grid connecting some building together at relatively short distance

NOTE 1: As standardized in Recommendation ITU-T L.1205 [i.1].

NOTE 2: It can be in AC or DC.

NOTE 3: In general nano grid is lower than 100 kW, micro grid can be of higher power. "Nano or micro grid" will be used in the present document.

nickel based battery: battery that uses nickel in electrode

peak shaving: technique used to shift a portion of an electrical load at a peak time of day to a non-peak time, helping in that to meet peak demands using alternate power sources such as gas supplies or energy storage

NOTE: Definition based on IADC UBO/MPD Glossary [i.21].

renewable energy: mainly non-fossil fuel converted into electricity

NOTE: As standardized in Recommendation ITU-T L.1205 [i.1].

EXAMPLE: Solar energy, wind, water flow, biomass which can be obtained from natural resources that can be constantly replenished.

self-consumption: consumption by an electricity consumer of its own energy production

smart grid: electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety

NOTE: As standardized in the European Commission Smart Grid Mandate [i.20].

3.2 Symbols

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

| | |
|----------------------|--|
| A (interface) | name of ICT/Telecom equipment -48 VDC power interface in ETSI EN 300 132-2 [1] |
| P | power feeding interface of up to 400 VDC defined in ETSI EN 300 132-3-1 [i.2] |

3.3 Abbreviations

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

| | |
|-----|--------------------------|
| AC | Alternative Current |
| AGM | Absorbent Glass Material |
| Ah | Ampere hour |

| | |
|---------------|---|
| BMS | Balancing Monitoring System |
| CAES | Compressed Air Energy Storage |
| CAPEX | Capital Expenditure |
| CO | Central Office |
| CPE | Customer Premises Equipment |
| DC | Direct Current |
| DoD | Depth of Discharge |
| EMC | Electro-Magnetic Compatibility |
| FTTCab | Fibre To The Cabinet |
| GHG | Green House Gas |
| ICT equipment | Information and Communications Technology equipment |

NOTE: Switches, transmitters, routers, servers, and peripheral devices used in telecommunication centres, data-centres and customer premises.

| | |
|-----|-----------------------|
| IoT | Internet of Things |
| LCA | Life Cycle Analysis |
| LCO | Lithium-Cobalt Oxide |
| LFP | Lithium Fer Phosphate |

NOTE: Fer is the French word for "Iron" in Mandeliev table for iron.

| | |
|------|---------------------------------|
| LIS | Lithium Sulfur |
| LMFP | Lithium Manganese Fer Phosphate |
| LMO | Lithium Manganese Oxide |
| LNO | Lithium Nickel Oxide |
| LTO | Lithium Titanate Oxide |
| LV | Low Voltage |
| M2M | Machine-to-Machine |
| MDF | Main Distribution Frame |
| MW | MegaWatt |
| NCA | Nickel Cobalt Aluminum |
| NGA | Next Generation Access |
| NMC | Nickel Manganese Cobalt |

NOTE: In the abbreviation of Lithium Nickel Manganese Cobalt Oxide, the letter L and O are omitted. Further details available at https://en.wikipedia.org/wiki/Lithium-ion_battery.

| | |
|-------|---|
| NiMH | Nickel metal Hydride |
| NiZn | Nickel Zinc |
| PHES | Pumped Hydroelectric Energy Storage sometimes also referred to as PSH |
| PSH | Pump Storage Hydroelectricity |
| PSOC | Partial State Of Charge |
| PSTN | Public Switched Telecommunication Network |
| REDOX | Reduction-Oxydation |
| SMES | Superconducting Magnetic Energy Storage |
| TCO | Total Cost Ownership |
| TE | Telecom Equipment |
| UPS | Uninterrupted Power Supply |
| Wh | Watt hour |

4 General Introduction of the need for electrical energy storage

4.1 Overview

This clause explains different use case of stationary batteries for ICT applications.

4.2 Short disturbance and dips filtering

A short autonomy can be added to cover short electrical supply interruptions, disturbances or dips, which is requiring a high power discharge rate energy storage. In general it is made with batteries or super-capacitors.

The rationale of this requirement for access network on good electric grid are provided in annex C.

NOTE: Batteries for this use case can be based on high power Lithium-ion or of NiMH or NiZn technology.

4.3 Increased reliability by adding autonomy to cover long grid outage

The rapid development of telecom networks compared to grid development in countries equipped with poor reliability or bad quality grids is driving the need to install more batteries to cover frequent and/or long grid outages.

Sites with good quality utility grid supply with minimal outage could be established by using low cost long autonomy rechargeable electric energy storage as alternative to engine generators or fuel cells.

NOTE: Compared to legacy lead acid a better Total Cost Ownership (TCO) could be obtained with new high temperature pure lead-acid or lead-carbon or Lithium-ion batteries, both with some thermal management. For very low cost or high capacity battery solution in near future flow batteries with large ionic salt tanks, low power sodium salt/carbon-manganese stack solutions or Zinc-air may be competitive. Other metal-air battery solutions need further development and as such are assigned for potential future use.

4.4 Self-consumption of renewable energy increased by storage for on grid and off grid systems

Energy transition towards less fossil fuels uses (oil, gas, coal, rare radioactive material) and less greenhouse gas GHG emissions is promoting the use of more renewable energy solutions that are directly associated with energy storage. This should be obtained at affordable cost and without losses of performance such as reliability compared to existing solutions. This use of batteries allows for the storage of excess of production of renewable energy during high production period (e.g. daylight photovoltaic production stored for night use). In this way, energy storage and the use of renewables are strongly linked together.

This evolution towards renewable energy with energy storage is seen on existing grids and for developing off-grid Telecom networks.

This relationship between renewables and energy storage is independent of the sizes of the site (small access sites, buildings).

There are many parameters and considerations (temperature range and management, of power, capacity, cycling lifetime, environmental consideration, cost, etc.) that will impact the choice of the technology.

4.5 Smart grid services with energy storage functionality and possible reliability increase

Energy transition is introducing demand-response regulation, where the user can contribute to the optimization of the electricity generation and grid power transmission capacities.

The first service that can involve battery is the power peak shaving associated with relatively short power load shifting for example to recharge the battery after the demand peak.

This approach is aiming at a controllable situation where energy usage can be shifted to times of renewable energy peak production i.e. for solar energy at mid-day. This is not clear at which extent this control is applicable to telecom site usage.

A complementary service is the fast support of the grid in power and frequency, by using a grid-tied inverter, where excess of renewable energy production can be injected back into the local utility grid.

This inclusion of energy storage at the telecom site allows for the storage of renewable energy produced on site but in addition allows for storage of energy bought from the utility grid at times of low cost that can, dependant on site usage, be sold back to grid utility with some profit.

The use of renewable energy with local site storage can form part of local nanogrid around the Telecom site e.g. for user service resilience. The Telecom site would host the batteries for the nanogrid. The additional batteries may also reduce the unavailability for critical sites by properly managing priorities of supply, this point being crucial to make this approach usable.

For this type of telecom site user case there are many considerations that could influence the technical, environmental and economic choice of a usable end solution as studied in Soogreen EU project [i.19].

4.6 M2M and IoT devices power supply

A part of the stationary M2M and IoT device is not connected to public AC grid or local DC power network and consumes too much to use primary batteries. In this case standalone energy (e.g. solar cells) associated with super-capacitors or rechargeable batteries in general of Lithium-ion or Nickel based type can be used.

The main parameters for selection of these energy storages are high cycling at defined temperature, high efficiency and low self-discharge, energy density, high reliability and defined life-time, low cost, low impact on environment in operation and end of life to avoid a difficult management.

4.7 Voltage interface of energy storage solutions

Energy storage solutions for use in ICT Direct Current installation described in clause 4 shall have a voltage range interface adapted feed power interface at input of stationary ICT equipment compliant with interface A (-48 V) [1] or interface P (up to 400 VDC) [i.2], or input for stationary CPE defined in [2] e.g. 12 V.

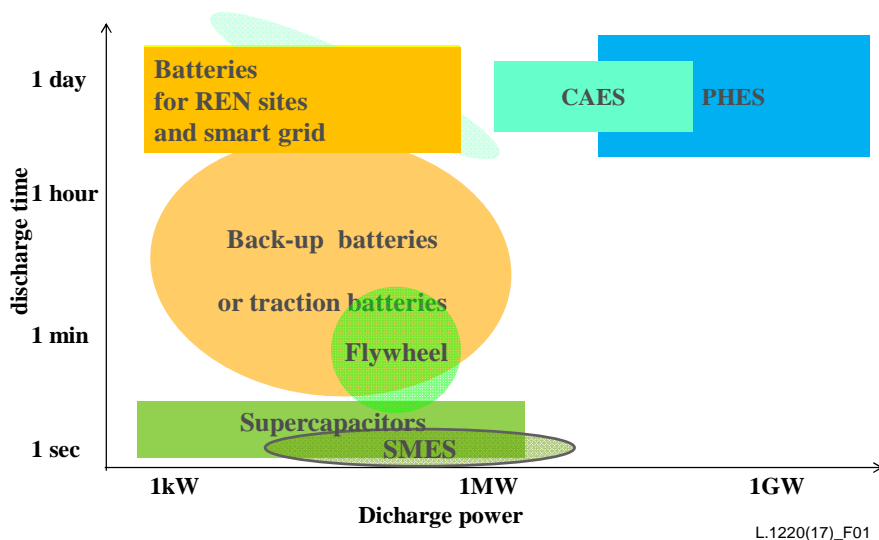
5 Evolution of energy storage

Energy storages are covered by many technologies using different disciplines in their development for best performance to suit their end applications as presented in Figure 5-1. This drawing gives only a rough idea of the range of performances.

Not all the energy storage technologies are relevant for the ICT sector. In the present document, the focus is on electrical storage technologies of power lower than 10 MW.

NOTE: The majority of technologies detailed in the Figure 5-1 are scalable to some extent however the pumped energy storage solution is better suited in terms of energy scaling/cost/infrastructure for utility energy and support to any ICT site would be indirect through the electricity grid. This is the same for magnetic storage having very high CAPEX and more suited to power grid utility application.

Major electricity Storage technologies situation



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NOTE: This drawing is based on information from [i.17] and [i.18].

Figure 5-1: Example of very general approach of energy storage system

Figure 5-1 shows an approximate representation of each storage type's technological characteristics. Some types, especially "batteries", encompass many technologies within the general shape.

Figure 5-2 shows the general classification of electric storage by intermediate stored energy (mechanical, electro-chemical).

| INTERMEDIATE ENERGY STORAGE | | | | |
|---|--------------------------------------|---|-------------------------------------|---|
| In electrical storage systems rechargeable from electricity | | | | |
| (1) large scale > 80% efficiency | | (2) medium scale > 50% efficiency | | |
| (3) short term | | (4) energy pulse | | |
| Mechanical storage | Electrostatic & EM storage | Chemical fuel (from electro-reduction) | Reversible Electro-Chemical systems | Heat storage |
| PEHS (1) | Capacitor (4, 3 with supercapacitor) | Gas fuels H ₂ , other derived from H ₂ , ... with fuel cell (2) | Rechargeable Batteries (2) | Sensible heat with thermoelectric generator (2) |
| CAES (1 and 2) | SMES (4) | Solid fuel metal in regenerative battery (2) | Flow battery (2) | Latent heat with heat turbine) (3) |
| Flywheel (3) | | liquid fuel Flow battery or reversible fuel cell (2) | | adiabatic CAES (1 and 2) |

NOTE: Figure based on [b-IEC WPstorage] presented in [b-ETSI EE 2015-storage solutions].

Figure 5-2: Electrical energy storage classification based on information of [i.9] and [i.14]

Table 5-1 gives an example of general electro chemical energy storage classification.

Table 5-1: Example of general view of electrochemical storage

| Reversible battery systems | | | | |
|----------------------------|---|---|--|--------------------------------|
| Naming | Internal energy storage | External energy storage (liquid tanks) Flow battery (REDOX) | Hot liquid metal battery | Metal-air or other gas battery |
| Lead-acid | Flooded, AGM, gel | | | |
| Alkaline nickel based | NiFe, NiCd, NiMH, NiZn, NiNi | | | Ni-H ₂ |
| Lithium based | Lots of Chemistry with Co, Fe, Ni, Mn, Ti, Sulphur, O, P, S, Si, and other additives Y, Li-Polymer Li-metal | | | Li-air |
| Sodium based | Na-ion NaSO ₄ , Mn | | NaS, NaNiCl ₂ | |
| Zn based | ZnMnO ₂ | Hybrid ZnBr | | Zn-air |
| Other (Mg, K, A) | Mg-ion, K-ion, Al-ion. | Vanadium Redox, SBr. | Gravitic separation of liquid electrodes | K-air, Mg-Air, Al-air |

More details can be found in annex B on the different battery technologies.

6 Selection method of energy storage for ICT stationary use

6.1 Overview

This clause presents a method for multi-criteria selection of energy storage technology and products solutions adapted to a use case and which evaluation and tests are required as suggested and applied in [i.19].

6.2 Selection method based on general criteria and complementary tests

In general a methodical approach should be defined to preselect adapted technology and products.

In this respect, a method is used to define a use case with the corresponding requirements and then match this with the energy storage technology and products characteristics.

Once completed, if existing standards, manufacturers tests results, environmental data (Life Cycle Analysis (LCA), etc.) are not sufficient for the preselected products any further relevant testing and analysis can be defined to complement the selection.

The proposed method will apply to all energy storage technologies and is described by a flow chart in Figure 6.2-1.

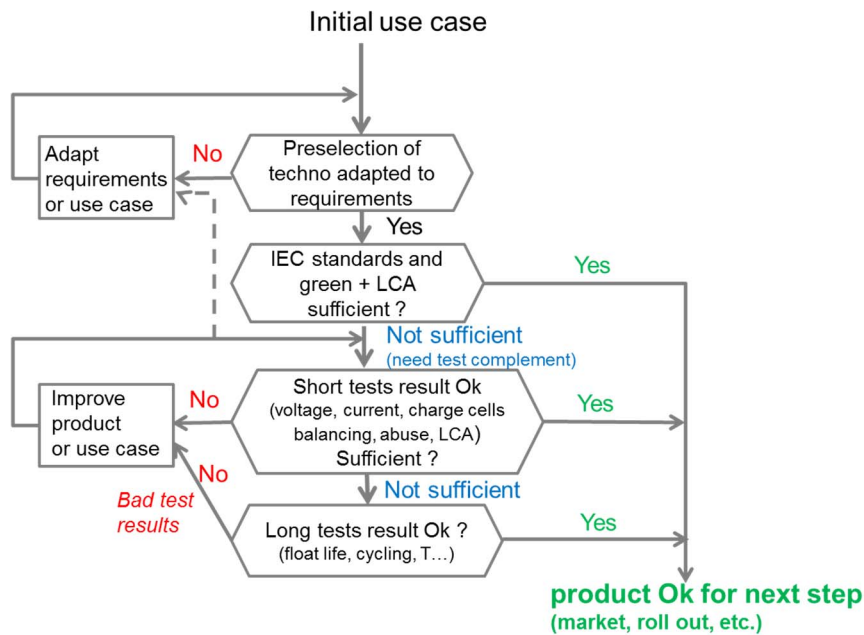


Figure 6.2-1: Flow chart of energy storage pre-selection and tests method for a use case

The following details a list of suggested application criteria for energy storage selection:

- Energy storage family type: battery or super-capacitors
- Technology types and their main properties
- Adaptation to system requirement:
 - functional availability (autonomy)
 - reliability, tolerance to default or abuse
 - electrical parameters voltage, voltage range, capacity, EMC
 - environment (temperature, vibration, etc.)
 - maintenance
 - environmental aspects, eco-design and recycling
 - physical size and weight
 - national rules and regulations
 - cost, etc.

Annex B gives an example of parametric multi-criteria approaches to assist in selection of battery/super-capacitor storage type compared to other energy storages type. It is completed by additional discrimination between the different battery technologies given defined requirements.

6.3 Detailed description of the main parameters of energy storage technology

The main parameters to consider for selecting an adapted technology of energy storage are the following:

- **Temperature range:** Extreme operational temperatures dictate the technical choice for reliable and safe operation. At worst a combination of conditions can be destructive on some technologies, e.g. at very low temperature lead-acid can freeze when discharged below defined DoD limit or at too high temperature some lithium technology will not survive.

- **Charge/Discharge time:** Often referred as a power rate - this rate being defined as ratio of energy storage capacity over charge/discharge time. For example a rate of $C_3/3$ represents the charge or discharge current, for 3 hours capacity.
- **Partial State Of Charge (PSOC):** This will indicate the use of the technology which is expected for example when lifetime shall not be affected by staying in partial state of charge without immediate recharge. For example, this is critical for intermittent renewable energy systems, where the battery can stay in PSOC for weeks.
- **Safety and sensibility level:** Safety is an essential requirement for energy storage to avoid dangerous uncontrolled conditions. For example Lithium-Ion technologies require a very strict control of cells voltage and temperature to insure safety and long reliable operation. Absorbent Glass Material (AGM) Lead acid technology is sensitive to thermal runaway and release hydrogen gas when overcharged and as such it requires strict venting rules.
- **Weight and power density:** This can be a critical requirement relevant to battery storage or site installation and indicates if any reinforcing the requirements are needed to the floor or the roof at site. This is particularly relevant in the case of roof-top or up-floor installation of mobile base stations.
- **Volume and volumetric energy:** The energy density of a battery is the capacity of the battery divided by either the weight of the battery, which gives the gravimetric energy density in Wh/kg, or by the volume, which gives a volumetric energy density in Wh/dm³ (or Wh/litre) A battery with a higher energy density will be lighter than a similar capacity battery with a lower energy density.

NOTE 1: Weight and volume are not obvious parameters to assess at battery level as some technologies are very good at cell level like hot sodium but penalized by thermal insulation material.

- **Efficiency:** This has several definitions as it can be the full capacity efficiency or the step efficiency at different state of charge. There is Columbic efficiency in electrical charge unit or an energy efficiency in energy unit.

NOTE 2: Efficiency is an important parameter for cycling application as the losses corresponds to energy loss and dissipated heat that can affect the energy storage location and support required or the impact on the other equipment in the same location.

- **Self-discharge and temperature dependence:** Internal chemical reactions or other leakage phenomenon (electrical, thermal, water evaporation, etc.) reduce the stored charge of the energy storage device without any connection between the poles (external and also internal electrodes in case of battery or super-capacitor). Temperature has a direct effect on this parameter for the majority of storage technologies. For example, low temperature operation of the battery increases internal resistance reducing the batteries capacity Whereas, high temperature operation although improving battery performance shortens the battery's life.

NOTE 3: The self-discharge is important parameter for charge retention of storage before use. At high temperature, some storage technologies can be fully self-discharged in a matter of weeks and this can be irreversible or require a costly restart process. In addition, a low self-discharge correspond to energy saving in the long run.

- **Cost constraints:** The comparison could be on relative CAPEX in cost per stored kWh of different energy storage. It can be also expressed in TCO in cost per cycled kWh over the lifetime. The comparison is inverted when considering CAPEX and TCO. Some storage technology can have a much higher CAPEX but offer a better TCO on the long run due to longer lifetime.
- **Lifetime:** A set of parameters is used to characterize the lifetime: the number of cycles at different defined Depth of Discharge (DoD), storage time before commissioning and operational lifetime. All of these are depending on temperature and use with different degradation mechanism.

7 Test methods

7.1 General introduction

There is a need for simple, effective and sufficiently precise test methods that provide results in a reasonable time frame, and complement methods described in existing standards [i.27] if these standards do not cover the full range of the tests. Examples of these standards are [i.12] for lead-acid batteries, [i.10], [i.11] for other battery technologies.

The present document focuses on generic tests for all technologies and while tests to for specific technologies are covered in the others parts.

In accordance with the parameters of energy storage technologies in clause 6.2 , the test given in Table 7.1-1 helps to check existing standards test results from manufacturers and to define the requirements additional use tests that are defined such as abuse, extreme, normal hard, normal soft and longest life category.

Table 7.1-1: Test severity depending on use case and corresponding defined requirements

| | abuse | extreme | normal hard | normal soft | longest life |
|--|-------|---------------------------------------|---------------------------|--|--|
| too long storage before use | | max permitted storage time before use | mid storage before use | short storage before use | short storage before use |
| over voltage in charge | | full discharge | deep discharge (e.g. 80%) | moderate cycling number and depth | few small cycling |
| under voltage in discharge and storage | | fast cycling with no rest time | fast recharge | adapted charge/discharge state and voltage | optimal charge/discharge state and voltage |
| over charge | | high charge voltage | high cycling | medium temperature | stable optimal temperature |
| over/under charge/discharge power | | extreme temperature | high low temperature | regeneration cycle ? | regeneration cycle? |
| extreme temperature | | persistent cell unbalance, | regeneration cycle? | | |
| | | recharge level (high or partial) | | | |

7.2 Test flowchart

The detailed test flowchart of Figure 7.2-1 should be followed in order to obtain repetitive results, allow observation and interpretation in order to determine the way forward and to define further tests or product improvements or changes.

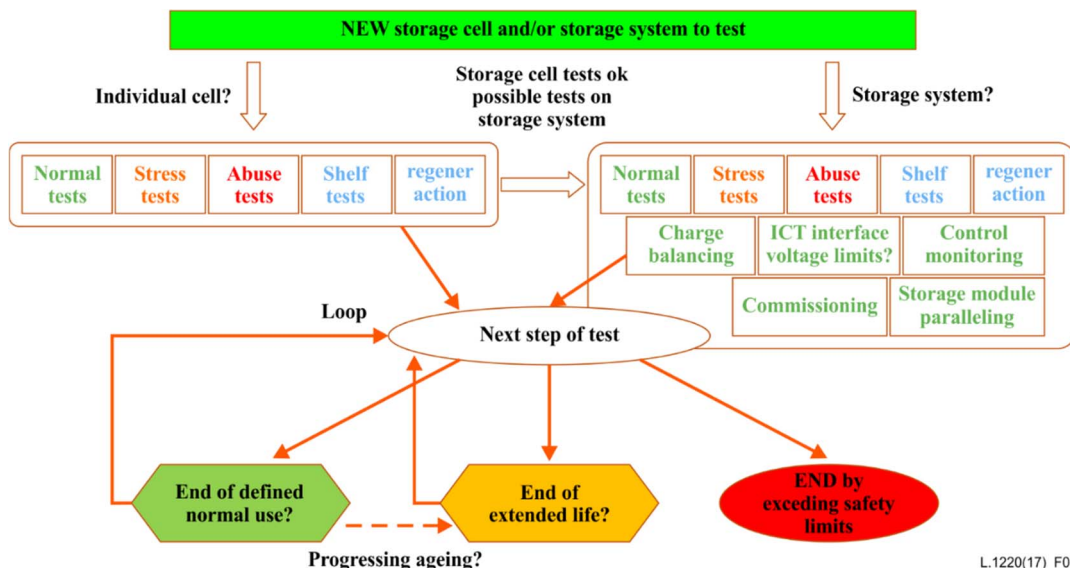


Figure 7.2-1: Flow chart of testing of energy storage and cell technology

The following explanation may help to understand the process defined in the flowchart of Figure 7.2-1.

- **Normal tests:** Cycling test at different charge/discharge current rates, back-up operation test, combined operation tests made at different temperatures.
- **Stress or abuse tests:** Additional stress over normal tests parameters values (voltage, current, temperature, depth of discharge, cell charge or voltage unbalance, etc.).
- **Shelf tests:** These tests correspond to transport and storage time possibly at high temperature between the manufacturing site and the installation site.

Tests acceleration:

The duration of tests can be variable depending on the nature and the condition of the tests. For example fast charge/discharge cycling tests may correspond to some months (e.g. 1 200 cycles of 1 h charge and 1 h discharge at 100 % DoD, i.e. 2 400 h, about 3 months), while testing back-up lifetime at 25 °C can last 10 years. It is clear that there is a need to accelerate tests by paralleling them or by activating ageing factors provided the test remains representative of real behaviour in normal use conditions.

- **Parallel tests:** Tests could be done in parallel on different cells or blocks to save time relative to serial tests.
- **Tests reliability:** For each test, more reliable results should be obtained by conducting tests on several cells or blocks.
- **Severe tests:** Extreme, stress and hard tests could be done before soft tests from the shorter to the longer, depending on requirement levels.

NOTE: It should be taken into consideration that extreme and stress tests might be destructive.

Balancing, monitoring, BMS tests:

- **Balancing information:** The type of balancing should be provided (in charge, in discharge, both, dissipative or not), and also balancing response time e.g. giving balancing current in % of cell capacity.
- **Balancing check-up:** Is initial start possible after storage of several months? Is full charge obtained and in which time? When cells are accessible, balancing with a discharged or a poor cell.
- **Monitoring functionality:** Battery status reporting information e.g. voltage, current, temperature, alarms, etc.
- **Other functionality:** Commissioning, remote access, paralleling, etc.

7.3 Additional considerations

7.3.1 Physical tests

The Evolution of weight (e.g. due to loss of water for non-Lithium battery) and the mechanical stability of casing are very important parameters to monitor in detail for energy storage device in particular in cycling use and extreme temperature use or temperature gradients.

7.3.2 Cycling tests and complexity of voltage settings

Testing should be closer to the real life scenario using active loads. Evaluation of the capacity of the battery or capacitor should be also controlled in Ah or Coulomb as it allows the evaluation of efficiency which is not only an important parameter for energy conservation but also an indicator of ageing.

The charge profile should have be defined in detail, not only considering simple evaluation but also real use case i.e. constant current, constant voltage, among other criteria such as variable intermittent energy charge and variable loads.

The discharge profile is also a critical parameter as the energy storage voltage range in charge and discharge shall be adapted to the voltage range defined at telecom power interface (e.g. in [1] for 48 V equipment or in [i.2] for up to 400 VDC equipment).

In general, when the battery is directly used without a converter, a narrower voltage range is defined to take into account the voltage loss in cables, for example 2 V in the case of -48 V, which means that minimum discharge voltage is in practice not defined as -40,5 V but as -43 V.

As a consequence the storage capacity shall be defined at minimum inside this narrow voltage range.

Annex A (informative): Energy Storage (battery, super-capacitor) World market evolution

World Market evolution in Figure A-1 is showing strong development of storage and of new battery technology to be considered.

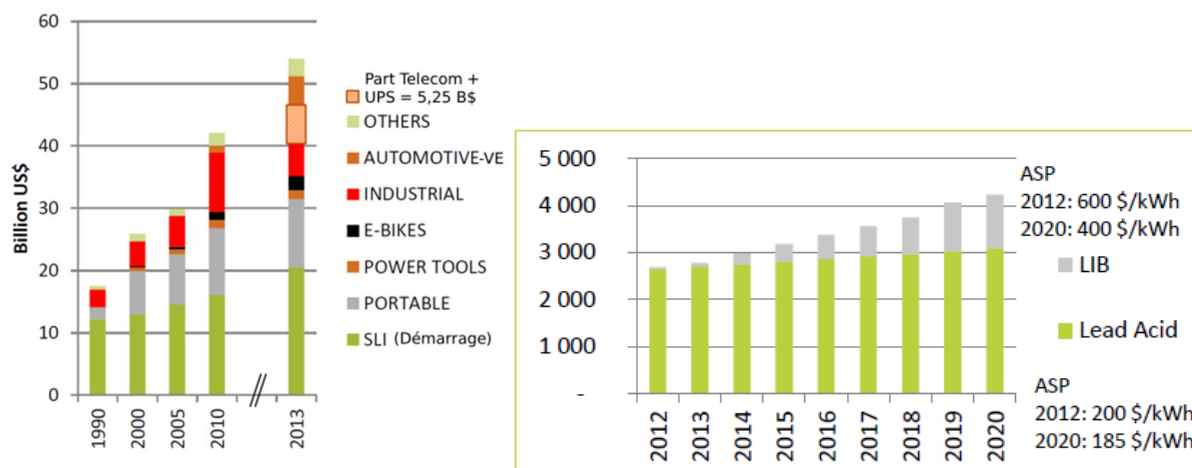


Figure A-1: World Battery Market Evolution and share estimation between lead-acid and lithium-ion technology for Telecom network and server UPS, based on Orange™ and Avicenne approach [i.23]

Annex B (informative): Helping approach for multi-criteria choice method between energy storage

This annex gives examples of parametric multi-criteria approaches that aids in the choice of a physical type of energy storage, for defined requirements of a use case.

It will lead to refine the choice of a technology of this energy storage, and for batteries of the chemistry e.g. battery of Lithium-ion technology with Lithium Iron Phosphate chemistry.

Figure B-1 is giving a general positioning of the energy storage technologies considering different parameters, some of them roughly corresponding to service or of power back-up or energy reserve such as reserve time, power, cycling ability, lifetime, or even cost versus performance.

Super-capacitors and battery technologies offer different power density, expected life time, temperature parameters are possible.

The storage parameters do not correspond to storage use for Datacentres or Telecom centres or distributed telecom equipment but gives a general overview.

For example, lead acid batteries are not obsolete storage technology especially when large energy capacities are required. Emergent technologies are particularly interesting for short power outage duration (large energy requirement for a short period of time) and if sited in harsh environments with high temperature, uncontrolled Partial State Of Charge (PSOC).

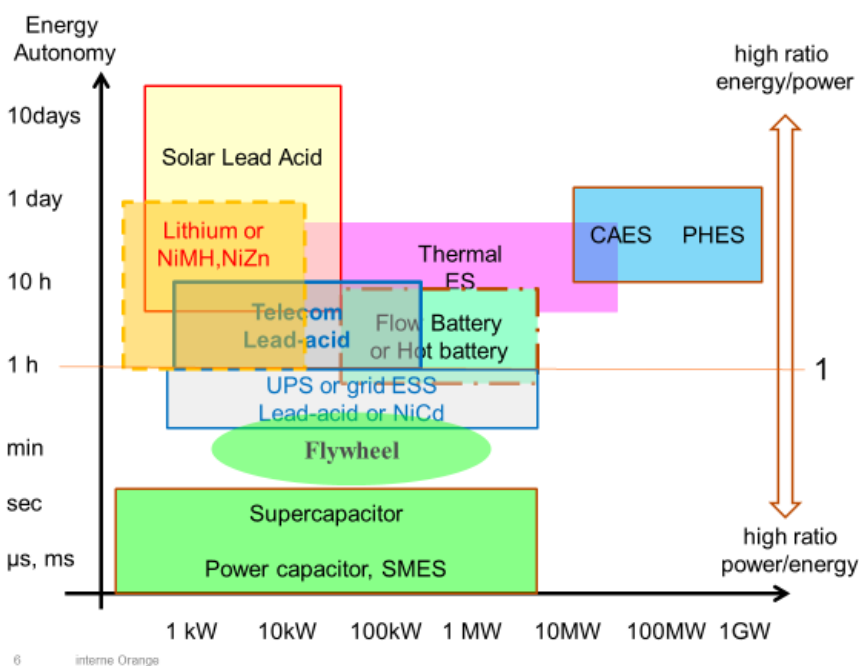


Figure B-1: Example of general comparison of energy storage service in terms of discharge time and power based on [i.17]

Table B-1 gives a general comparison of battery and other energy storage technologies focused on use for ICT equipment.

Table B-1: General comparison of energy storage solutions (mainly electrochemical)

| Maturity | Techno | ++ | + | - | -- |
|-----------------------|---------------------|--|----------------------------------|--------------------------------|-----------------------|
| | Pb | Cost | Charge Management | Green - Temperature | |
| | NiFe | | Life Expectancy | Efficiency | Water Consumption |
| | NiCd | Deep Discharge Cycle-Life | Low Temp Perf. | Cost (CAPEX) | |
| | NiMH | Safety | Cycling | Charge Management | Cost (CAPEX) |
| | Li Ion | Cycling + PSOC | Energy Density | Field Experience | Cost (CAPEX) backup |
| | NaS | Cycling | No Ambient Temperature Effect | Safety Issues | Cost (CAPEX) |
| | NaNiCl2 | Cycling | No Ambient Temperature Effect | Efficiency | Thermal Management |
| | NiZn | Green + Cost | Cycling | Field experience | |
| | RedOx | No Self discharge + Energy/Power independant | No Ambient Temperature Effect | Efficiency - Energy density | |
| | Metal Air | Energy density | Green | Charge Management | Cycling |
| H2+Electro- lyseur | High energy storage | Green + Abondant | Efficiency - Safety | Cost (CAPEX) | |
| Fly Wheel | Power + Cycling | Green + Abondant | Safety | Energy Performance | |

NOTE: In Table B-1, for each technology, four criteria are evaluated from "++" the best to " - - " the worst (or in colour scale : green, white, yellow, orange, red) based on [i.15].

Tables B-2, B-3, B-4 and B-5 give general comparison of batteries.

Table B-2: Example of general comparison of battery technologies based on [i.16]

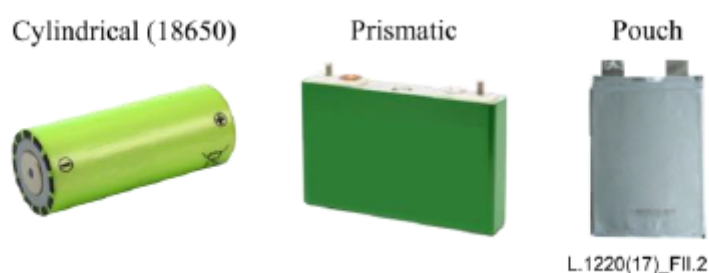
| Specification | Lead-acid | NiCd, NiMH, NiZn | Li-ion (many different technologies) |
|--------------------------------------|--|--|---|
| Available since | Late 1800 | NiCd and NiZn early 1900, NiMH 1990 | 1990 |
| Specific Energy Wh/kg | 30/50 | 45/120 | 60-250 |
| Specific Power kW/kg | < 1 | < 1 | < 3 |
| Cell voltage | 2V | 1,2 to 1,6V | 2,3 to 4V |
| Cycle life (at 80 % capacity) | 300 to 1 500 | 300 to 2 000 | |
| Charge voltage limit | 2,3 to 2,6V | 1,5 to 2V | 3 to 4,2V |
| Overcharge tolerance | high | moderate | very low to low |
| Temperature | -20 to 60 °C | -40 to +60 °C | 0 to 60°C heater below |
| Safety requirements | Thermally stable, Remove H2 from charge | Thermally stable | Mandatory protection of each cells against low and high voltage and temperature |
| Lifetime | up to 20 years at 20 °C 5 to 10 at 40 °C (cells balancing by overcharge) | up to 20 years weak (15 at 40 °C) (no or simple cells balancing) | up to 10-20 years with complex cell balancing |
| Energy Efficiency and self-discharge | 80 % 2 to 10 % | 70 to 85 % 5 to 30 % | 90 to 95 % 3 % in electronic |
| Toxicity | High | very high for NiCd Low for NiZn | High for organic electrolyte |
| Relative cost | 1 to 3 | 3 to 7 over cost of rare earths for NiMH | 5 to 10 Costs of chemistry, electronics and manufacturing |

Table B-3 focuses more on Lithium battery technology diversity. Table B-3 relates to technologies mostly used for portable device.

Table B-3: Example of general comparison of Lithium battery technologies

| Battery chemistry | Safety | Power density | Energy density | Cycles | Costs |
|-------------------|--------|---------------|----------------|-----------|--------|
| Iron Phosphate | High | High | Medium | High | Medium |
| Nickel manganese | Medium | Medium | Medium | Low | Low |
| Manganese | Medium | Medium | Medium | Low | Low |
| Titanate | High | High | Low | Very high | Medium |
| Cobalt Oxide | Low | Low | High | Low | Low |

The information on different shapes of lithium batteries are shown in Figure B-2.



NOTE: 18 650 is a very common size of cylindrical Lithium cell (18 mm diameter and 65,0 height).

Figure B-2: Different common shapes of lithium batteries

Table B-4 mostly relates to electric vehicle applications where Energy density versus safety are major parameters in addition to operating conditions of power, temperature range and lifetime under cost constraint. It appears that the safer technologies are in the lower voltages and energy density range.

Table B-4: Example of multicriteria classification of Li-ion battery technologies

| Name | LCO | LNO | NCA | NMC | LMO spinel | LFP, LMFP | LTO anode | LIS R&D | Lmetal R&D |
|--------------------|--------------------|--------------------|---|--|--------------------|---------------------|--|---------|------------|
| Cathode | LiCoO ₂ | LiNiO ₂ | LiNi _x Co _y Al _z | LiNi _x Mn _y C _{o_z} | LiMnO ₂ | LiFePO ₄ | any e.g. LMO, | | |
| Anode | Graphite | Graphite | Graphite | Graphite | Graphite | Graphite | Li _x Ti _y O _z | | |
| Mean cell Voltage | 3,6-3,8V | 3,6V | 3,6V | 3,7-4V | 3,8 | 3,3V | 2,4 | 2,1V | 2.7-3V |
| Wh/kg | 100-180 | 150 | 140-200 | 160-200 | 135-220 | 100-130 | 55 | 300-400 | 100-150 |
| Discharge rate | 4C | 1C | 10-20C | 4-20C | 5 – 15C | 5-20C | 20C | | |
| Safety (- / 0 / +) | - | 0 | 0 | 0 | 0 | ++ | ++ | ? | ? |
| Lifetime (years) | 5-8 | ? | 10-20 | 7-10 | 10-12 | 8-12 | 20 | | |
| Cycles 80 % DoD | 1 000 | ? | 4 000 | 3 000 | 2 000 | 3 000 | 10 000 | 100 | 3 000 |
| Cost | ++ | + | + | + | + | + | - | ? | - |

NOTE: The source of Table B-4 is a simplified analysis based on different documents e.g. from the Soogreen European project.

Annex C (informative): Rationale for very short autonomy on good grid obtained by super-capacitor or high power rechargeable battery

Annex C gives rationale for using very short autonomy mainly in access network on very good grid with very few interruptions longer than of seconds or minutes.

In many standards, alternative energy solution have been described with short autonomy for access network [i.4] and [i.3].

They can refer to grid report showing improvement on availability in Europe as shown later and also in order to reduce environmental impact of battery as in report [i.5].

Statistical data on electrical power supply availability, from the Low Voltage (LV) public grid (mains) in various European countries, can be a relevant element for TE's power supply protection strategy, in an NGA networks context. In the following Figures C-1 and C-2, data on public electrical power grid availability, from main European countries, are shown (including Medium Voltage and Low Voltage interruptions - source [i.6] and [i.7]). Data change from country to country, but a general trend of improvement in power grid availability is observed.

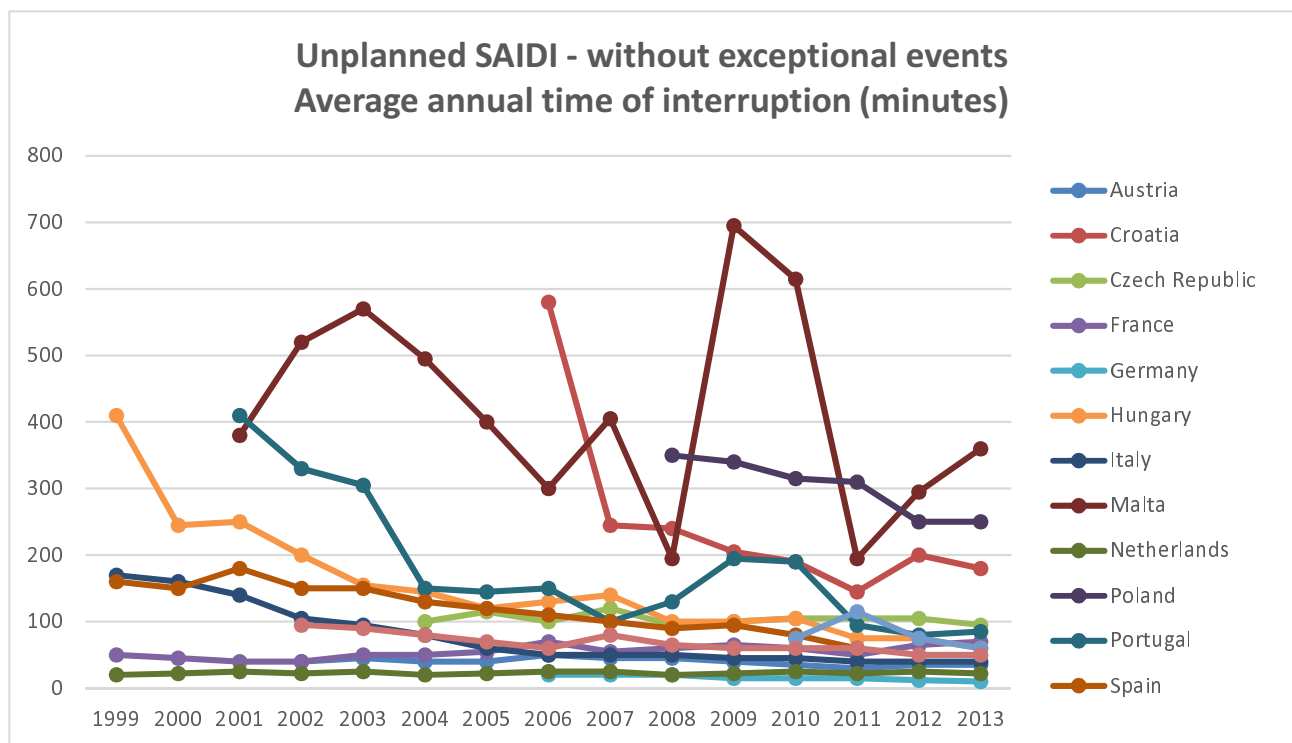


Figure C-1: Data on power grid availability for European countries

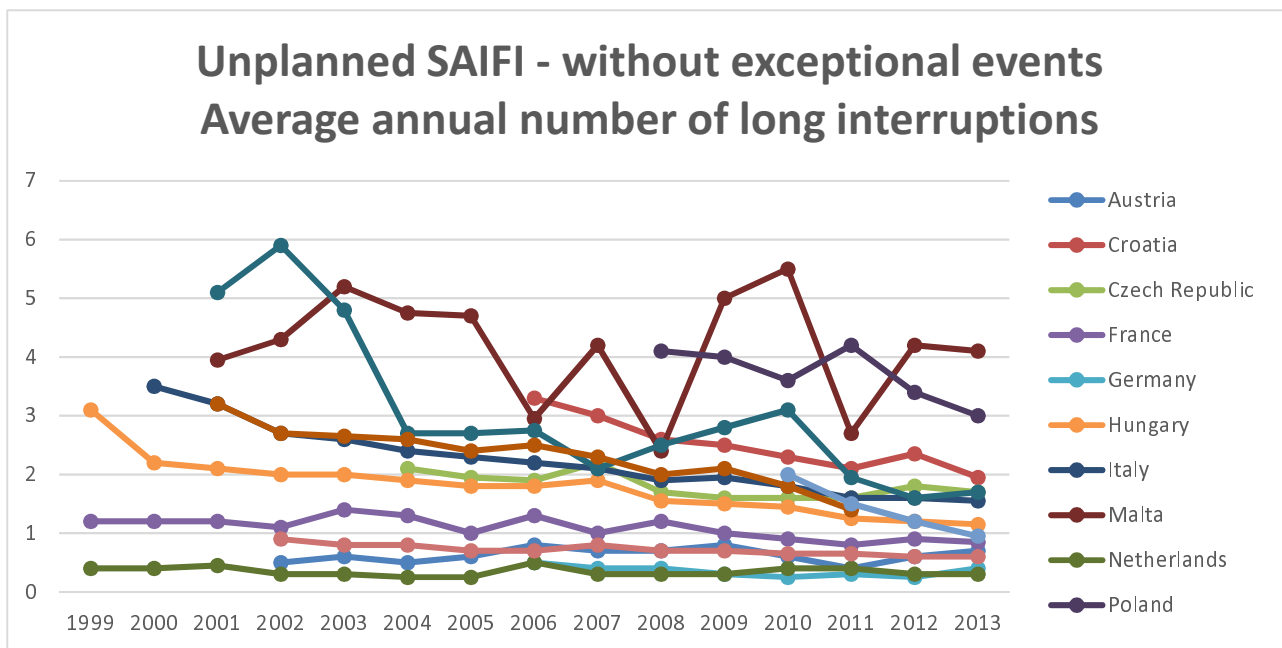


Figure C-2: Data on power grid availability for European countries

In a similar way, the following Figures C-3, C-4 and C-5 give equivalent information for the Italian electrical LV power grid [i.7].

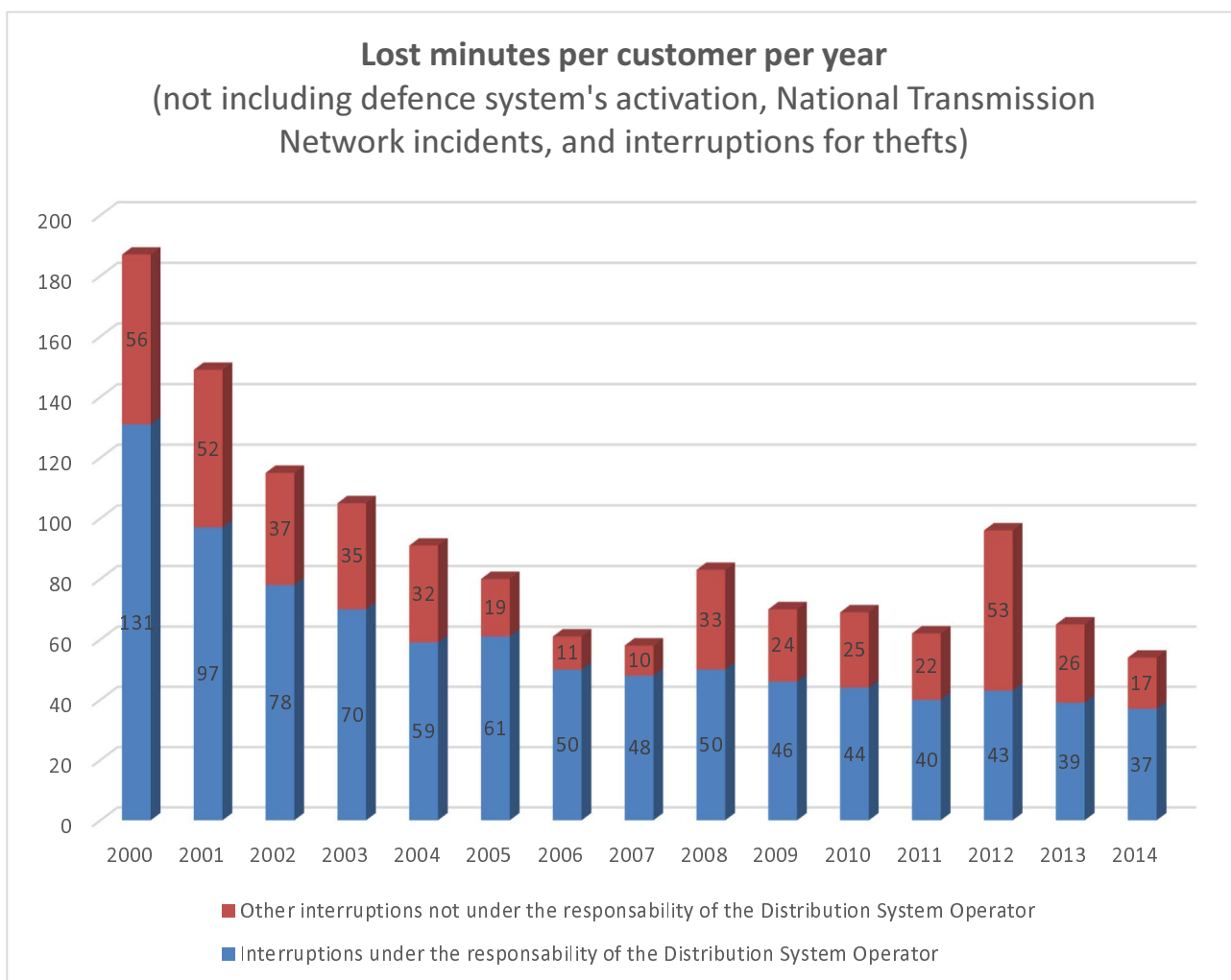


Figure C-3: Data on power grid availability for Italy

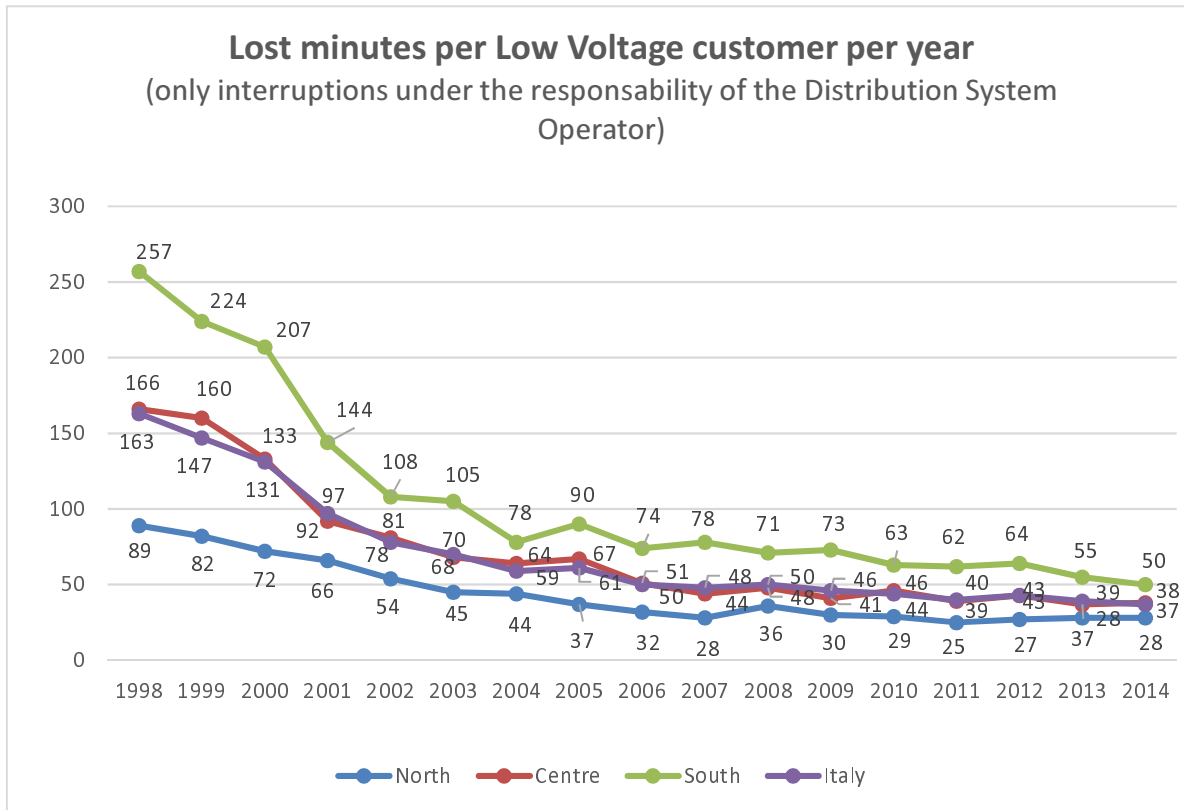


Figure C-4: Data on power grid availability for Italy

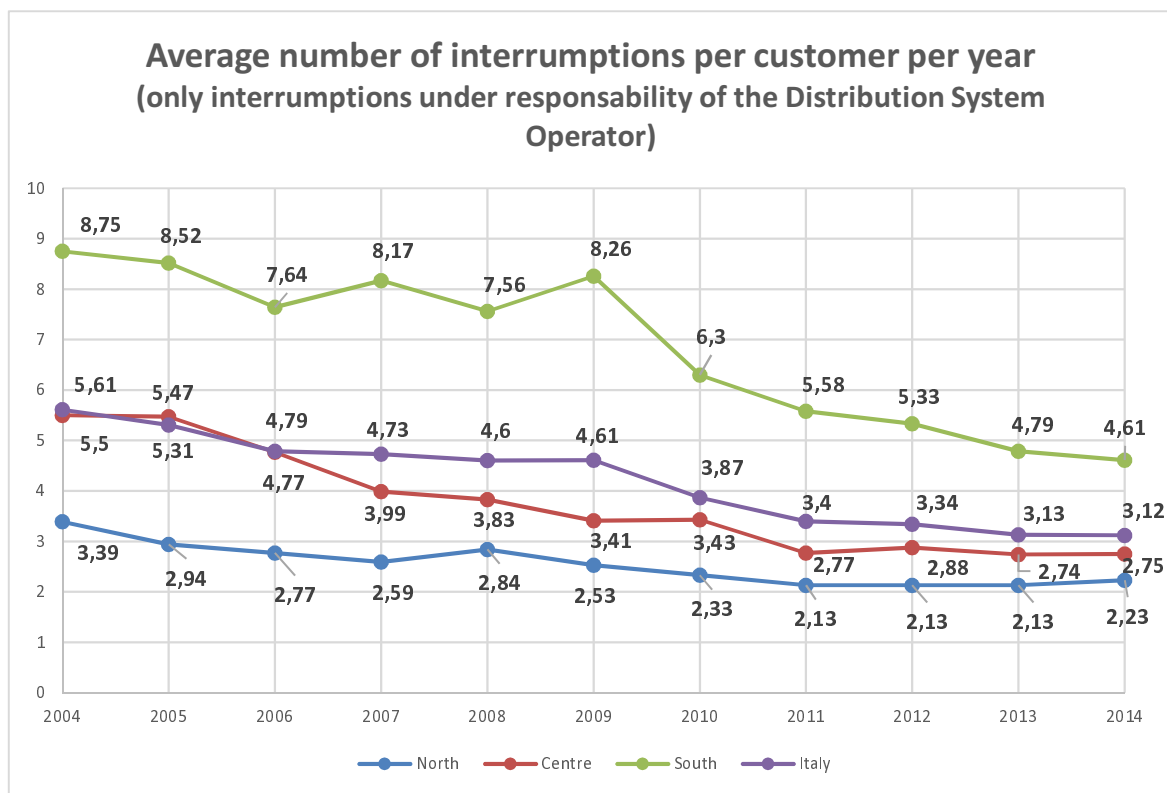


Figure C-5: Data on power grid availability for Italy

Figure C-6 shows the comparison of the total unavailability of classic PSTN and of the new NGA networks (FTTCab architecture, with or without adoption of mains' micro-interruption coverage - up to 1 sec - by super-capacitor adoption), as an example for the Italian network. The total unavailability is, as a basis, primarily related to access network, Main Distribution Frame (MDF) in Central Office (CO) and network equipment reliability. New fibre based NGA networks give, in general, an higher availability and reliability, with respect to traditional access network technologies.

In PSTN scenario, no extra unavailability from public mains is taken into account (since PSTN has coverage of power outage through Central Office's batteries). In NGA network scenario, unavailability from public mains and related ICT reboots has also to be taken into account. As shown from the analysis in Figure C-6, the adoption of a power conditioning unit (super-capacitor for 1 second coverage of micro-interruptions of mains) can significantly reduce the total unavailability of NGA network (with a sensible reduction due to ICT reboots), giving a total level of unavailability lower than traditional PSTN from Central Office.

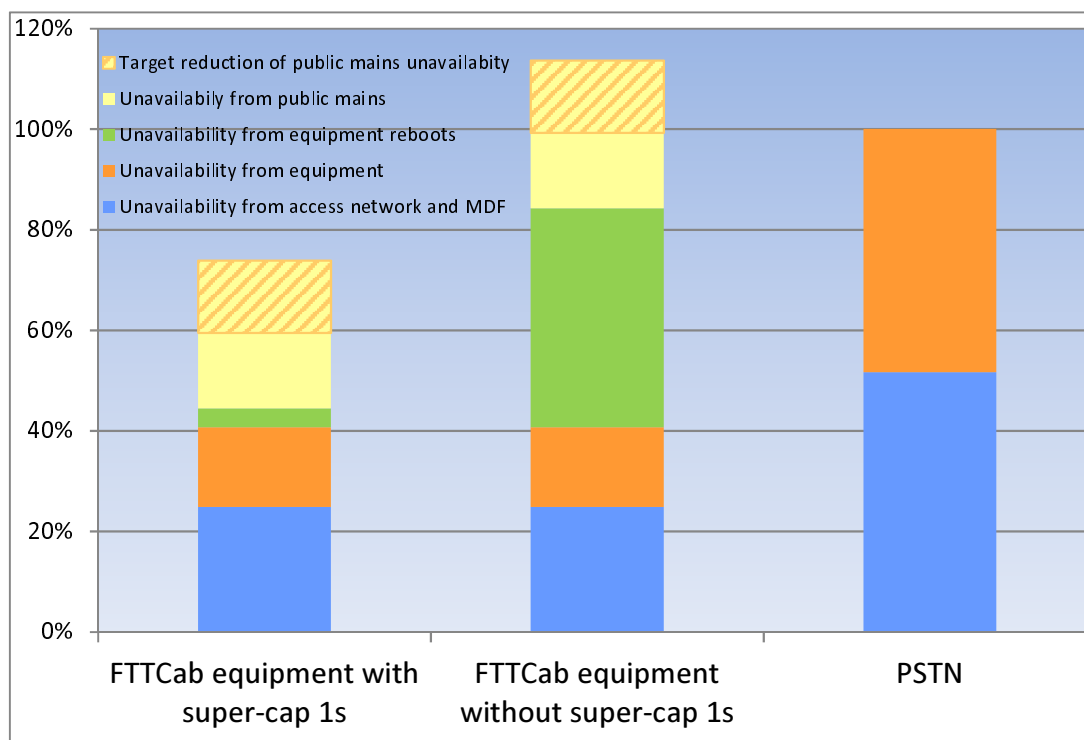


Figure C-6: Unavailability of new NGA network (FTTCab) versus classic PSTN

History

| Document history | | |
|-------------------------|-------------|-------------|
| V1.1.1 | August 2019 | Publication |
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