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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

Innovative energy storage technology for stationary use – Part 1: Overview of energy storage

Recommendation ITU-T L.1220

ITU-T L-SERIES RECOMMENDATIONS

ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

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Recommendation ITU-T L.1220

Innovative energy storage technology for stationary use – Part 1: Overview of energy storage

Summary

Recommendation ITU-T L.1220 introduces an open series of documents for different families of technologies (e.g., battery systems, super-capacitor 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.

Identified parts of this Recommendation series, Innovative energy storage technology for stationary use, are:

– Part 1: Overview of energy storage;

– Part 2: Battery systems;

– Part 3: Supercapacitor technology.

History

Edition	Recommendation	Approval	Study Group	Unique ID[*]
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Keywords

Battery, direct current, double layer capacitor, energy storage, rechargeable battery, secondary battery, supercapacitor.

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[*] To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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Introduction

Until early 2000, battery technology has been dominated by lead-acid for stationary and motive uses (e.g., factory fork lifts, engine starters). Nickel-metal hydride (NiMH) and lithium have been used for mobile devices, portable tools and partially for electric vehicles. They 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 vehicles for public and private transport. The latest battery research has been directed toward technology enhancements that support an increase in distance travelled by vehicles 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 advantages in terms of reduced cost, safety, higher energy density levels and quicker charging. These include solid state batteries, aluminum ion, lithium sulfur and metal air. These strong developments of battery technologies can be applied to the 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 assortments, but is best known as the hydrogen fuel cell for which a very high-power density of 0.7 $W.cm^{-2}$, or higher, is possible, depending on operating conditions. Car manufacturers are considering extending the range of batteries with general optimization in hybrid solutions for fuel cells, 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 (https://ec.europa.eu/energy/en/topics/renewable-energy/renewable-energy-directive) states that the EU is to meet at least 20% of its total energy needs with renewable energy by 2020. This is to be achieved through the attainment of individual national targets by member states.

In a revision of the directive, the EU targets at least 27% renewable energy of their final energy consumption by 2030.

Depending on the energy mix, the existing electric grid can accept an average injection of up to 10 to 30% of renewable energy by only adding big regional energy storages. For example, water pumped-storage hydroelectricity (PSH) or air compressed 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 water 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 EU borders where there is a need for smaller local storage solutions. In general, these solutions comprise of electro-chemical batteries.

In an attempt to make ICT sites more autonomous or interactive with the local utilities (e.g., peak shaving, demand response), 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 float batteries to cyclic batteries, and in addition where site power requirements dictate, short-term storage solutions, such as supercapacitors, should be considered.

With the development of new sectors, such as Internet of Things (IoT) and machine-to-machine (M2M) technologies, uninterrupted stationary energy supplies have become more and more important where energy consumption is too great for using primary batteries given their 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 [b-IEC WPstorage] and other presentations and publications such as [b-IRES + ESE 2016-T&E], [b-ETSI EE 2015-storage solutions], [b-Elsevier 2016-ESS applications], [b-battery BU-107], [b-battery BU-205], [b-ENEA], [b-Soogreen].

The trend toward the use of more cyclic battery technologies and supercapacitors is illustrated in the international battery market evolution presented in Appendix I.

To this end, and to facilitate the choice of adapted storage solutions for stationary use in the ICT sector, simple and effective methods were developed in this series of Recommendations. They should give results in a reasonable time period, introduced in this Recommendation.

Detailed information and test methods will be given in the next parts for each family of technologies which are under development, i.e., Part 2 and Part 3.

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

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

The intention of these evaluation methods is not as a substitute for, but rather to complement the IEC standards on batteries on energy storage safety, factory tests, etc. These standards include [b-IEC 60896-X] for stationary lead-acid batteries, [b-IEC 62619] and [b-IEC 62620] for alkaline batteries or other non-acid electrolyte batteries, or further work on new energy storage technologies (e.g., other battery technologies, fly-wheel). Other useful IEC standards defining basic rules of graphical marking or other basic electrical safety are also listed in the bibliography.

This Recommendation was developed jointly by ETSI TC EE and ITU-T Study Group 5, and is respectively published by ITU and ETSI as Recommendation ITU-T L.1220 and ETSI Standard ETSI TS 103 553-1, which are technically equivalent.

Recommendation ITU-T L.1220

Innovative energy storage technology for stationary use – Part 1: Overview of energy storage

1 Scope

This Recommendation identifies the main needs and applications of stationary electrical energy storage for information and communication technology (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 supercapacitors;
- technologies types and their main properties;
- adaptation to requirements (e.g., functionalities, technology availability, electrical characteristics, environmental adaptation, maintenance type, cost);
- national or regional rules and regulations.

The Recommendation highlights the need for evaluation methods that are complementary to existing battery standards as they allow different time-frames including shorter tests compared to common energy storage industry tests.

This Recommendation is Part 1 of a series of Recommendations that cover energy storage technologies (e.g., battery, supercapacitor) applicable to stationary telecom/ICT equipment used in telecom networks, data centres and customer premises equipment (CPE).

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1001]	Recommendation ITU-T L.1001 (2012), *External universal power adapter solutions for stationary information and communication technology devices*.
[ITU-T L.1200]	Recommendation ITU-T L.1200 (2012), *Direct current power feeding interface up to 400 V at the input to telecommunication and ICT equipment*.
[ETSI EN 300 132-2]	ETSI EN 300 132-2 V2.3.6 (2011), *Environmental Engineering (EE); Power supply interface at the input to telecommunications and datacom (ICT) equipment; Part 2: Operated by −48 V direct current (dc)*.

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms define elsewhere:

3.1.1 electrical equipment [b-IEC 60050-826]: 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.).

3.1.2 ICT equipment [ITU-T L.1200]: Information and communication equipment (e.g., switch, transmitter, router, server, and peripheral devices) used in telecommunication centres, data-centres and customer premises.

3.1.3 load shifting [b-IADC]: Moving an entire load from a peak time to an off-peak time.

3.1.4 nano grid, micro grid [b-ITU-T L.1205]: A local area grid connecting some buildings together at relatively short distances. It can be in AC or DC. In general, a nano grid is lower than 100 kW and a micro grid can be of higher power.

3.1.5 renewable energy [b-ITU-T L.1205]: Mainly non-fossil fuel converted into electricity (e.g., solar energy, wind, water flow, biomass) which can be obtained from natural resources that can be constantly replenished.

3.1.6 smart grid [b-EU mandate]: A Smart Grid is an 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.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 back-up energy storage: Energy storage system able to feed electricity to equipment of an information and communication technology or telecom site in case of unavailability or insufficiency of power source (electric grid or local source) to match the load demand.

3.2.2 demand response: Utility demand to final consumers (households or businesses) providing response in manual or automatic mode, giving flexibility to the electrical system by voluntarily changing the consumer's electrical 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. as defined in [b-eurelectric].

3.2.3 energy storage: Action or means to store energy for future use.

3.2.4 −48 VDC: −48 Volt Direct Current voltage range at the power interface of ICT equipment, based on [ETSI EN 300 132-2].

3.2.5 lithium-based battery: Battery that uses lithium electrodes.

3.2.6 nickel-based battery: Battery that uses nickel electrodes.

3.2.7 peak shaving: Technique used to shift a portion of an electrical load at a peak time of day to a non-peak time, thus helping to meet peek demands through the use of alternate power sources such as gas supplies or energy storage as defined in [b-peak shaving].

3.2.8 interface P: Up to 400 VDC Power feeding interface, based on [ITU-T L.1200].

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

3.2.10 up to 400 VDC: Up to 400 Volt Direct Current voltage range at the power interface of ICT equipment (equivalent to voltage range defined in [b-ETSI EN 300 132-3-1], as described in [ITU-T L.1200].

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AC	Alternating Current
AGM	Absorbent Glass Material
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
EU	European Union
FTTCab	Fibre To The Cabinet
ICT	Information and Communication Technology
IoT	Internet of Things
LV	Low Voltage
M2M	Machine-to-Machine
MDF	Main Distribution Frame
NGA	Next-Generation Access
NiCd	Nickel-Cadmium
NiMH	Nickel-Metal Hydride
NiZn	Nickel-Zinc
PHES	Pumped Hydroelectric Energy Storage
PSH	Pumped-Storage Hydroelectricity
PSOC	Partial State of Charge
PSTN	Public Switched Telephone Network
SMES	Superconducting Magnetic Energy Storage
TE	Telecom Equipment
TCO	Total Cost of Ownership

5 Conventions

5.1 A (interface)

[ETSI EN 300 132-2]: ICT equipment −48 VDC power interface.

5.2 A3 (interface)

[b-EN 300 132-3-1]: ICT/telecom equipment (TE) up to 400 VDC power interface in ETSI.

6 General introduction of the need for electrical energy storage

This clause explains various use cases for stationary batteries in ICT applications.

6.1 Short disturbance and dips filtering

A short autonomy can be added to cover brief electrical supply interruptions, disturbances or dips, requiring high-power discharge rate energy storage. In general, it is composed of batteries or supercapacitors.

The rationale of this requirement for access networks on good electric grids is provided in Appendix III.

NOTE – Batteries for this use case can be based on high-power lithium-ion or with nickel-metal hydride (NiMH) or nickel-zinc (NiZn) technology.

6.2 Increased reliability by adding autonomy to cover prolonged grid outages

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

Sites providing good quality utility grid supply with minimal outages could be established by using low-cost, long-running autonomous rechargeable electric energy storage as an alternative to engine generators or fuel cells.

NOTE – Compared to legacy lead-acid batteries, a better total cost of 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 solutions, in the 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.

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

Energy transition toward using less fossil fuels (oil, gas, coal, rare radioactive material) and producing less greenhouse gas (GHG) is promoting the use of more renewable energy solutions that are directly associated with energy storage. This storage should be obtained at an affordable cost and without loss of performance when compared to existing solutions. The use of batteries allows for storing the excess renewable energy produced during high-production periods (e.g., daylight photovoltaic production stored for night use). In this way, energy storage and the use of renewable sources are strongly linked together.

This evolution toward renewable energy with energy storage is present on existing grids and in developing off-grid telecom networks.

The relationship between renewable sources and energy storage is independent of the size of the site (small access sites, buildings).

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

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

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

The first service that can involve a 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 also 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. It is not clear to what 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.

The inclusion of energy storage at a telecom site allows storing of renewable energy produced on site, and also allows for storage of energy bought from the utility grid during low cost times that can, depending on site usage, be sold back to the utility grid with a profit.

The use of renewable energy with local site storage can form part of the 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 which is crucial to make this approach usable.

For this type of telecom site use case, there are many considerations that could influence the technical, environmental and economic choice of a usable end solution [b-Soogreen].

6.5 Machine-to-machine and Internet of Things devices power supply

A part of the stationary machine-to-machine (M2M) and Internet of Things (IoT) device is not connected to the public alternating current (AC) grid or local direct current (DC) power network, and consumes too much to use primary batteries. In this case, a standalone energy solution (e.g., solar cells) associated with supercapacitors or rechargeable batteries, generally lithium-ion or nickel-based type, can be used.

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

6 6 Voltage interface of energy storage solutions

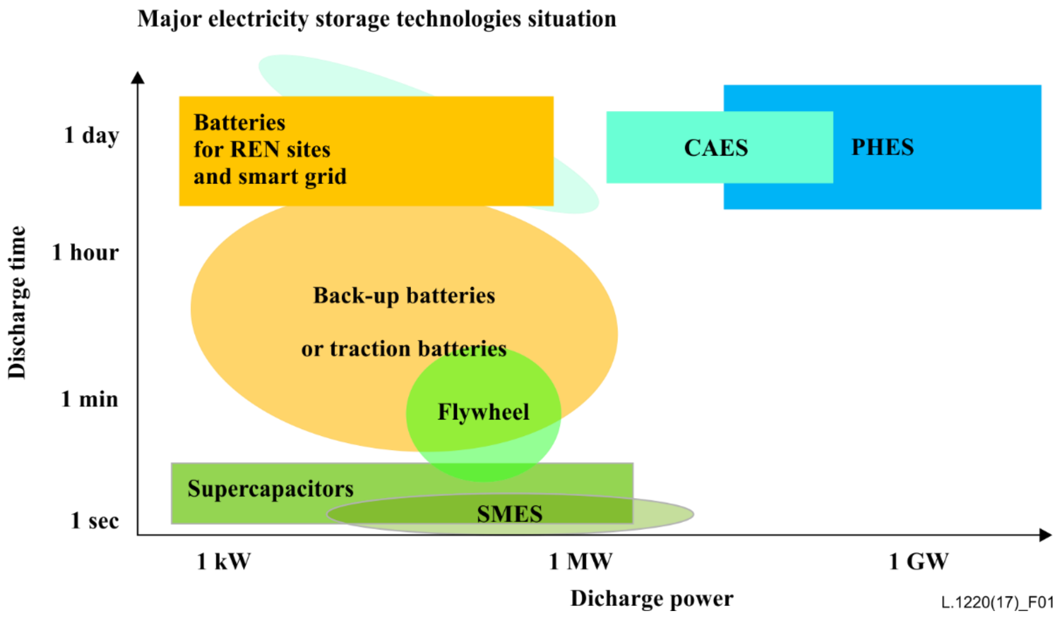
Energy storage solutions used in ICT DC installations, considered in clause 7, shall have a voltage range adapted to feed the power interface at the input of stationary ICT equipment compliant with interface A (−48 V) [ETSI EN 300 132-2] or interface A3 (up to 400 VDC) [ITU-T L.1200], or input for stationary CPE defined in [ITU-T L.1001] e.g., 12 V.

7 Evolution of energy storage

Energy storage is covered by many different technologies using various disciplines in their development to achieve best performance to suit their end applications, see Figure 1. This figure gives a rough idea of the range of performances.

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

NOTE – The majority of technologies detailed in Figure 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 capital expenditure (CAPEX) which is more suited to power grid utility applications.

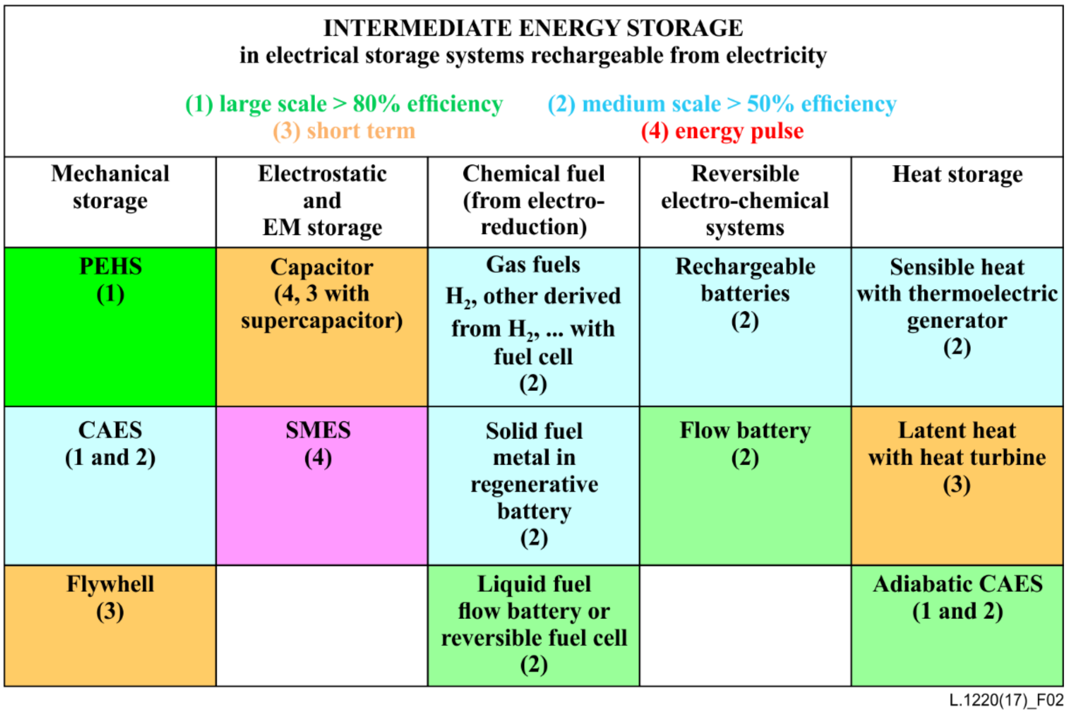


NOTE – Figure based on [b-ESA] and [b-ENEA].

Figure 1 – General overview of energy storage systems

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

Figure 2 shows the general classification of electric storage by intermediate stored energy (e.g., 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 and 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)
Flywhell (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 2 – General electrical energy storage classification

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

Table 1 – 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-H2
Lithium based	Lot of Chemistry with Co, Fe, Ni, Mn, Ti, Sulfur, O, P, S, Si, … and other additive Y,… Li-Polymer Li-metal			Li-air
Sodium based	Na-ion NaSO4, Mn		NaS, NaNiCl2	
Zn based	$ZnMnO_2$	Hybrid ZnBr		Zn-air
Other (Mg, K, Al…)	Mg-ion, K-ion, Al-ion, …	Vanadium Redox, SBr, …	Gravitic separation of liquid electrodes	K-air, Mg-Air, Al-air

Additional details on various battery technologies can be found in Appendix II.

8 Selection method of energy storage for ICT stationary use

This clause presents a method for a multi-criteria selection of energy storage technology and product solutions adapted to a use case for which evaluation and tests are required.

8.1 Selection method based on general criteria and complementary tests

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

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

Once completed, if existing standards, manufacturer test results, and environmental data (e.g., life-cycle analysis (LCA)) 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 the flow chart in Figure 3.

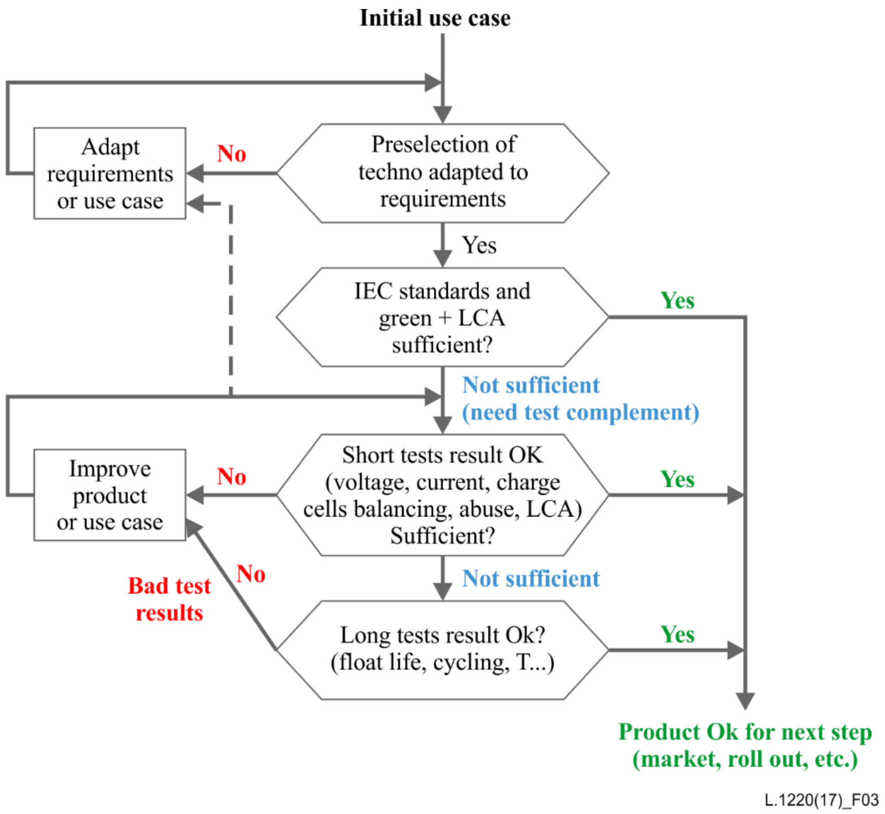


Figure 3 – Flow chart of energy storage preselection and test method

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

- Energy storage family type: battery or supercapacitors.
- 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 (e.g., temperature, vibration);
  - maintenance;
  - environmental aspects, eco-design and recycling;
  - physical size and weight;
  - national rules and regulations;
  - cost.

Appendix II provides examples of a multi-criteria approach to assist in the selection of battery/supercapacitor storage type as compared to other energy storage types. It is completed with an additional classification of the different battery technologies given the defined requirements.

8.2 Detailed description of the main parameters of energy storage technology

The main parameters to consider when 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 to some technologies, e.g., at very low temperature, lead-acid can freeze when discharged below a defined depth of discharge (DOD) limit, or at too high a temperature some lithium technology will not survive.

- **charge/discharge time**: Often referred to as power rate, defined as the ratio of energy storage capacity over charge/discharge time. For example, a rate of $C_3/3$ represents the charge or discharge current, for a three-hour capacity.
- **partial state of charge (PSOC)**: This indicates the use of the technology that is expected, for example, when the lifetime of the storage solution is not affected by staying in a PSOC without immediate recharge. This is critical for intermittent renewable energy systems where the battery can stay in a 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 cell voltage and temperature to ensure a safe and reliable operation. Absorbent glass material (AGM): Lead-acid technology is sensitive to thermal runaway and can release hydrogen gas when overcharged, thus requiring strict venting rules.
- **weight and power density**: This can be a critical requirement relevant to battery storage or site installation and indicates if reinforcement requirements are needed for the floor or roof where the batter is located. This is particularly relevant in the case of roof-top or top-floor installations 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/dm^3 (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, for example, hot sodium but is penalized by thermal insulation material.

- **efficiency**: This has several definitions such as full-capacity efficiency or step efficiency at different states of charge. There is Coulumbic 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 the support required or the impact on the other equipment in the same location.

- **self-discharge and temperature dependency**: Internal chemical reactions or other leakage phenomenon (e.g., electrical, thermal, water evaporation) reduce the stored charge of the energy storage device without any connection between the poles (external and also internal electrodes of batteries or supercapacitors). Temperature has a direct effect on this parameter for most storage technologies. For example, at low temperatures a battery increases internal resistance, thus reducing the battery's capacity. Whereas, at high temperatures battery performance will improve, but battery life will be shortened.

  NOTE 3 – Self-discharge is an important parameter in charge retention of batteries before being used. 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, low self-discharge corresponds to energy saving in the long run.

- **cost constraints**: Cost comparisons could be on relative CAPEX in cost per stored kWh of energy storage. It can also be expressed in TCO in cost per cycled kWh over the lifetime of the storage. This comparison is inverted when considering CAPEX and TCO comparison. Some storage technologies can have a much higher CAPEX, but offer a better TCO in the long run due to the longer lifetime of the energy storage.

– **lifetime**: Lifetime is characterized by a set of parameters including: the number of cycles at different defined DODs, storage time before commissioning, operational lifetime. All of these are temperature dependent and conform to different degradation mechanisms.

9 Test methods

9.1 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, if these standards do not cover the full range of the test. Examples of these standards are [b-IEC 60896-X] for lead-acid batteries, [b-IEC 62619] and [b-IEC 62620] for other batteries.

Part 1 of this series of Recommendations focuses on generic tests for all technologies, while tests for specific technologies are covered in the other parts.

In accordance with the parameters of energy storage technologies listed in clause 8.2, the test severity given in Table 2 helps to check existing standards test results from manufacturers and to define the requirements for additional use tests defined as: abuse, extreme, normal hard, normal soft and longest life.

Table 2 – Test severity depending on use case and corresponding defined requirements

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

L.1220(17)_Table01

9.2 Test flowchart

The detailed test flowchart shown in Figure 4 should be followed in order to obtain repetitive results, for observation and interpretation to determine and to define further tests or product improvements or changes.

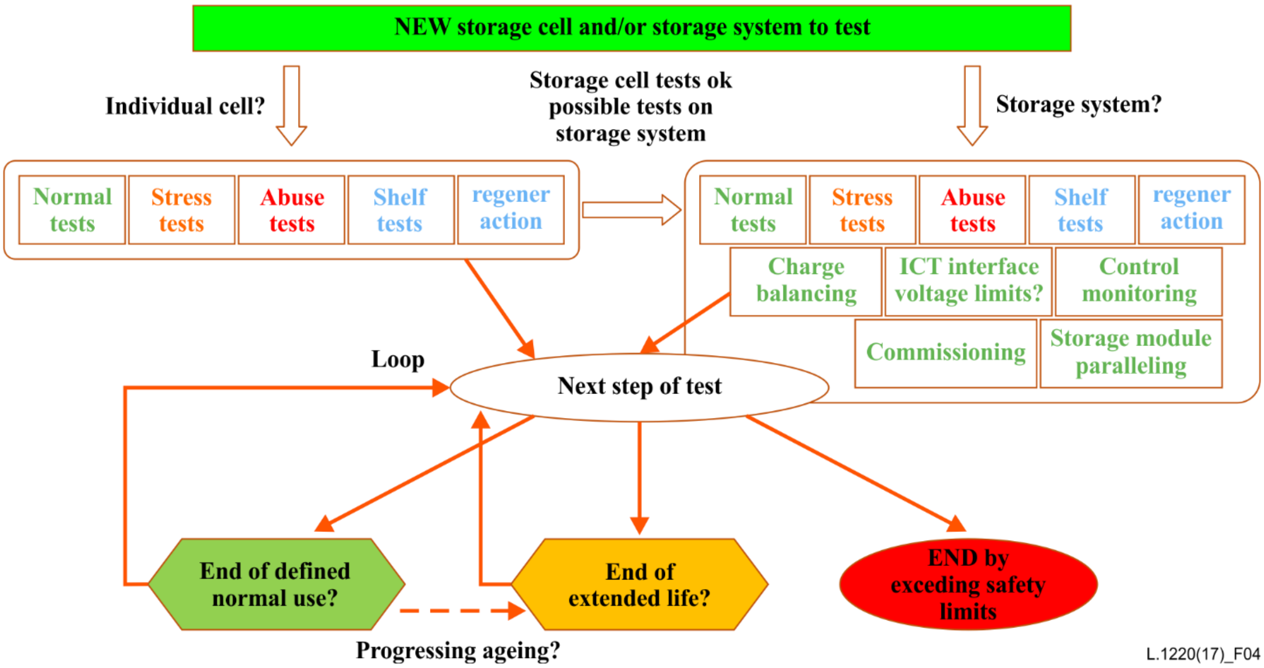


Figure 4 – Flow chart of testing of energy storage and cell technology

The following explanation provides understanding to the process defined in Figure 4.

- **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 test parameter values (e.g., voltage, current, temperature, depth of discharge, cell charge or voltage unbalance).
- **shelf tests**: These tests correspond to transport and storage time, possibly at high temperatures, between the manufacturing site and the installation site.

Test acceleration

The duration of tests can be variable, depending on the nature and condition of the tests. For example, testing fast charge/discharge cycles may take many months (e.g., 1200 cycles of 1 h charge/1 h discharge at 100% DOD, i.e., 2400 h, takes 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 running them in parallel or by activating ageing factors provided the test remains representative of real behaviour in normal use conditions.

- **parallel tests**: Tests could be run in parallel on different cells or blocks to save time relative to serial tests.
- **test 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 run before running soft tests, from shorter to longer, depending on requirement levels.

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

Balancing monitoring system (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 what time? When cells are accessible, balancing with discharged or poor cells.
- **monitoring functionality**: Battery status reporting information, e.g., voltage, current, temperature, alarms.
- **other functionality**: Commissioning, remote access, paralleling, etc.

9.3 Additional considerations

9.3.1 Physical tests

The evolution of weight (e.g., due to loss of water for non- lithium batteries) and the mechanical stability of casing are very important parameters to monitor for energy storage devices, in particular during use in cyclic, extreme temperature or temperature gradients.

9.3.2 Cycling tests and complexity of voltage settings

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

The charge profile should have to be defined in detail, considering simple evaluation and real use cases, 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 (in [ETSI EN 300 132-2] for −48 V equipment or in [ITU-T L.1200] for up to 400 VDC equipment). As a consequence, the storage capacity shall be defined at minimum in this voltage range unless voltage converter is used between the storage and the telecom load.

In general, when the battery is used without a converter, a narrow 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 rather as −43 V.

As a consequence, the storage capacity shall be defined at minimum inside this voltage range unless it is planned to use a voltage converter between the storage and the telecom load.

Appendix I

Energy storage (battery, supercapacitor) world-market evolution

(This appendix does not form an integral part of this Recommendation.)

The world battery market evolution, see Figure I.1, shows strong development in storage capacity and new battery technologies.

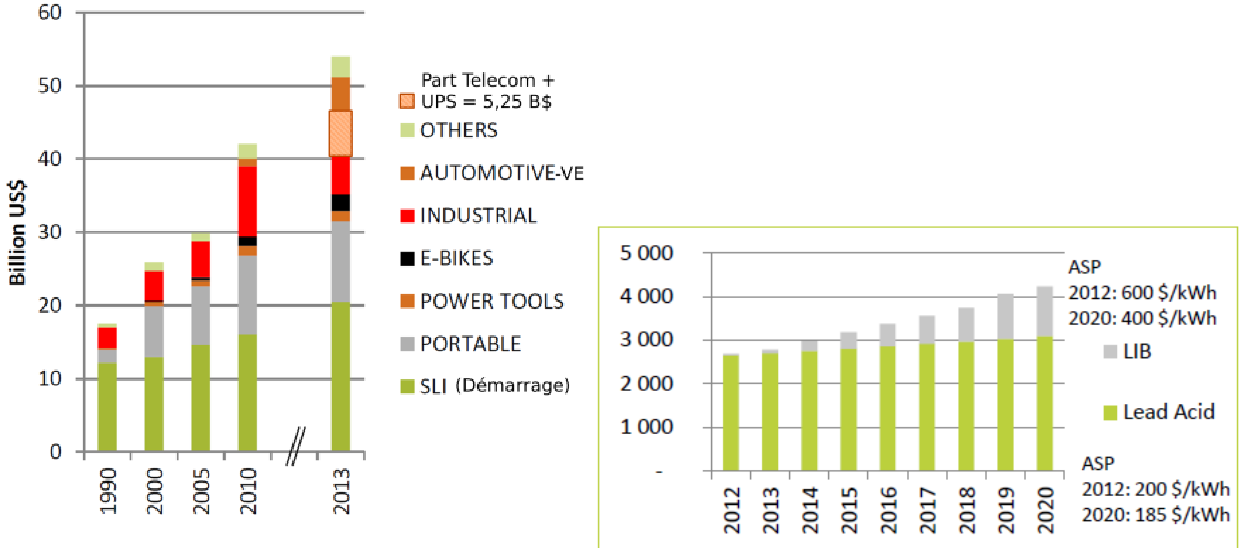


Figure I.1 – World battery market evolution and share estimation between lead-acid and lithium-ion technology for Telecom network and server UPS, based on Orange and Avicenne approach [b-Avicenne]

Appendix II
Multi-criteria approach to choosing energy storage

(This appendix does not form an integral part of this Recommendation.)

This appendix gives examples of parametric multi-criteria approaches to choosing a physical type of energy storage for defined requirements of a use case.

These approaches will help refine the choice of an energy storage technology. For batteries, it will help in the selection of chemistry, e.g., selecting a battery of lithium-ion technology with lithium iron phosphate chemistry.

Figure II.1 compares energy storage technologies considering different parameters, some of them roughly corresponding to service, power back-up or energy reserve, such as reserve time, power, cycling ability, lifetime, etc., or even cost versus performance.

Supercapacitors and battery technologies offer different power densities and have different expected lifetime temperature parameters.

The storage parameters give a general overview, and do not correspond to storage use for data centres, telecom centres or distributed telecom equipment.

For example, lead-acid batteries are not an obsolete storage technology, especially when large energy capacities are required. Emergent technologies are particularly interesting for short power outages (large energy requirement for a short period of time) and if sited in harsh environments with high temperatures and uncontrolled PSOC.

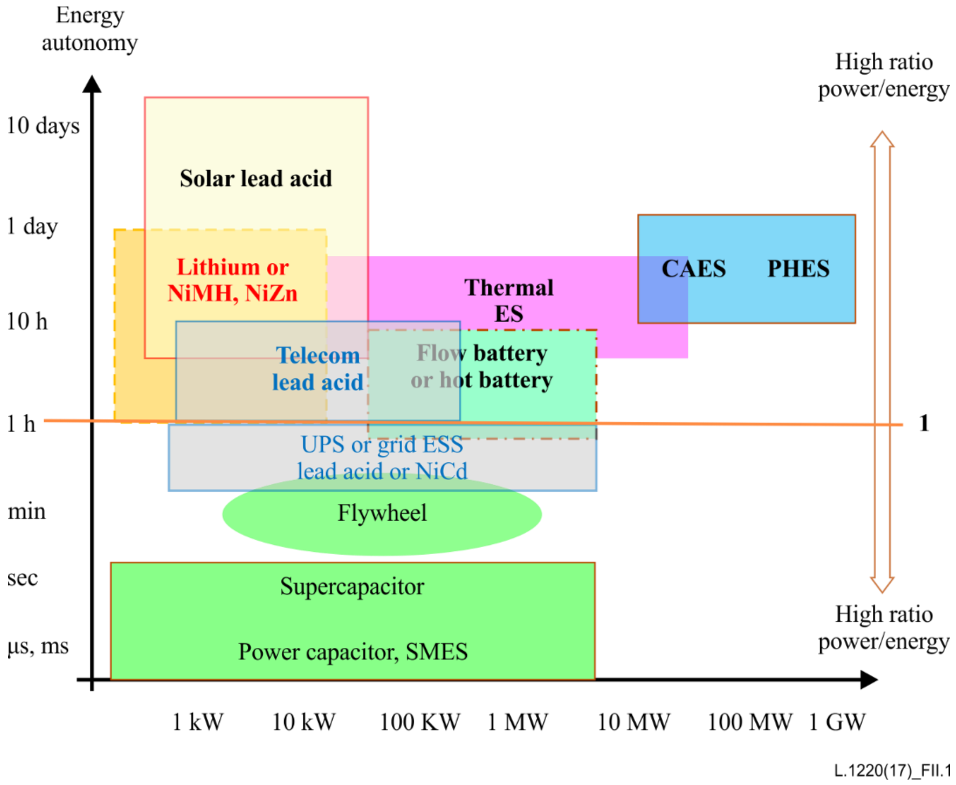
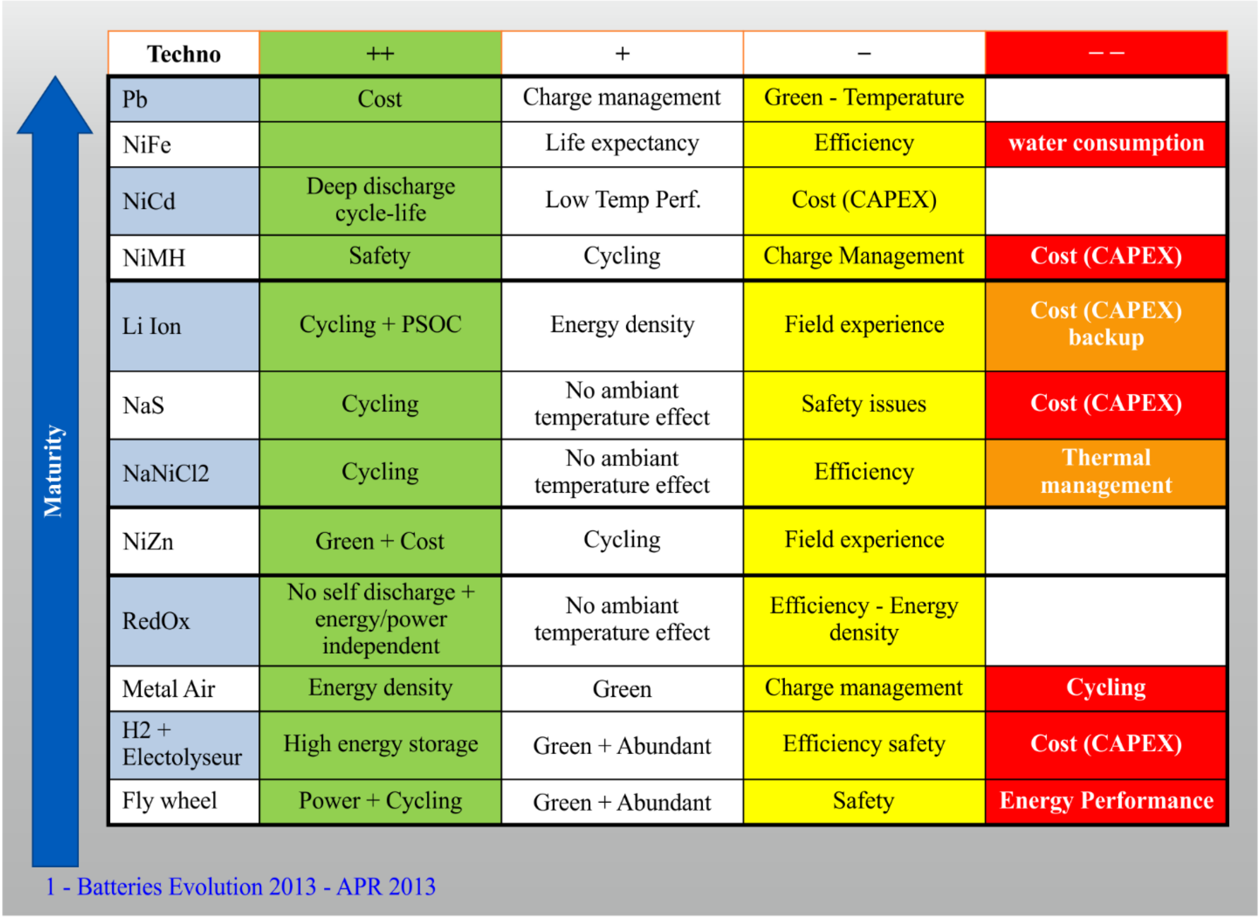


Figure II.1 – Example of general comparison of energy storage service in terms of discharge time and power, based on [b-ENEA]

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

Table II.1 – General comparison of energy storage solutions (mainly electrochemical) from [b-ETSI EE 2015-storage solutions]



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 ambiant temperature effect	Safety issues	**Cost (CAPEX)**
NaNiCl2	Cycling	No ambiant temperature effect	Efficiency	**Thermal management**
NiZn	Green + Cost	Cycling	Field experience	
RedOx	No self discharge + energy/power independent	No ambiant temperature effect	Efficiency - Energy density	
Metal Air	Energy density	Green	Charge management	**Cycling**
H2 + Electolyseur	High energy storage	Green + Abundant	Efficiency safety	**Cost (CAPEX)**
Fly wheel	Power + Cycling	Green + Abundant	Safety	**Energy Performance**

1 - Batteries Evolution 2013 - APR 2013

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NOTE – For each technology, four criteria are evaluated from "++", the best, to" – – ", the worst (or in colour scale: green, white, yellow, orange, red).

Tables II.2, II.3 and II.4 give a general comparison of batteries.

Table II.2 – Example of general comparison of battery technologies based on [b-battery BU-107] and [b- battery BU-205]

Specification	**Lead-acid**	**NiCd, NiMH, NiZn**	**Li-ion (many different technologies)**
Available since	late 1800s	NiCd and NiZN early 1900s, NiMH 1990	1990
Specific energy Wh/kg	30/50	45/120	60-250
Specific power kW/kg	< 1	< 1	< 3
Cell voltage	2	1.2 to 1.6 V	2.3 to 4 V
Cycle life (at 80% capacity)	300 to 1500	300 to 2000	
Charge voltage limit	2.3 to 2.6 V	1.5 to 2 V	3 to 4.2 V
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 cell 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 nickel-cadmium (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 II.3 focuses on the diversity of lithium battery technology. Table II.3 relates to technologies used mostly for portable devices.

Table II.3 – Example of general comparison of lithium battery technologies

Lithium battery chemistry	**Safety**	**Power density**	**Energy density**	**Cycles**	**Costs**
Iron phosphate (LFP)	high	high	medium	high	medium
Nickel manganese cobalt (NMC)	medium	medium	medium	low	low
Manganese oxide (LMO)	medium	medium	medium	low	low

Table II.3 – Example of general comparison of lithium battery technologies

Lithium battery chemistry	Safety	Power density	Energy density	Cycles	Costs
Titanate (LTO)	high	high	low	very high	medium
Cobalt oxide (LCO)	low	low	high	low	low

The different shapes of lithium batteries are shown in Figure II.2.

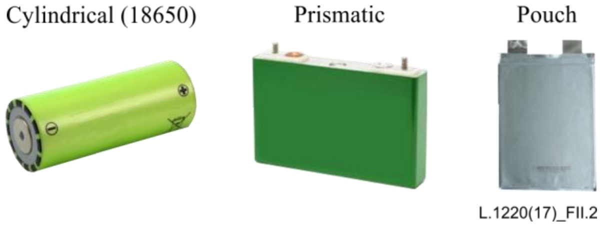

Figure II.2 – Different shapes of lithium batteries

Table II.4 relates mostly to electric vehicle applications where energy density vs. safety are major parameters in addition to operating conditions of power, temperature range and lifetime under cost constraints. It appears that the safer technologies are in lower voltage and energy density ranges.

Table II.4 – Example of multi-criteria classification of Li-ion battery technologies

Name	LCO	LNO	NCA	NMC	LMO spinel	LFP, LMFP	LTO anode	LIS R&D	Lmetal R&D
Cathode	$LiCoO_2$	$LiNiO_2$	$LiNi_xCo_yAl_z$	$LiNi_xMn_yCo_z$	LiMnO2	$LiFePO_4$	any e.g. LMO,		
Anode	Graphite	Graphite	Graphite	Graphite	Graphite	Graphite	$Li_xTi_yO_z$		
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
Dicharge 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	1000	?	4000	3000	2000	3000	10000	100	3000
Cost	++	+	+	+	+	+	-	?	-

NOTE – The source of this table is an analysis made based on different documents, including [b-Soogreen].

Appendix III

Rationale for very short autonomy on good grids obtained by supercapacitor or high-power rechargeable battery

(This appendix does not form an integral part of this Recommendation.)

This appendix outlines the rationale for using very short autonomy, mainly in access networks on good grids with few interruptions longer than a few seconds or minutes.

In many standards, alternative energy solutions have been described with short autonomy for access networks [b-ETSI TR 102 532], [b-EN 302 099].

They can refer to grid reports showing improvement in availability in Europe, as shown later, and also in order to reduce the environmental impact of batteries as in [b-RSE report].

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 a next-generation access (NGA) network context. In Figures III.1 and III.2, data on public electrical power grid availability, from main European countries, are shown (including medium voltage and LV interruptions – source [b-CEER]. Data changes from country to country, but a general trend of improvement in power grid availability is observed.

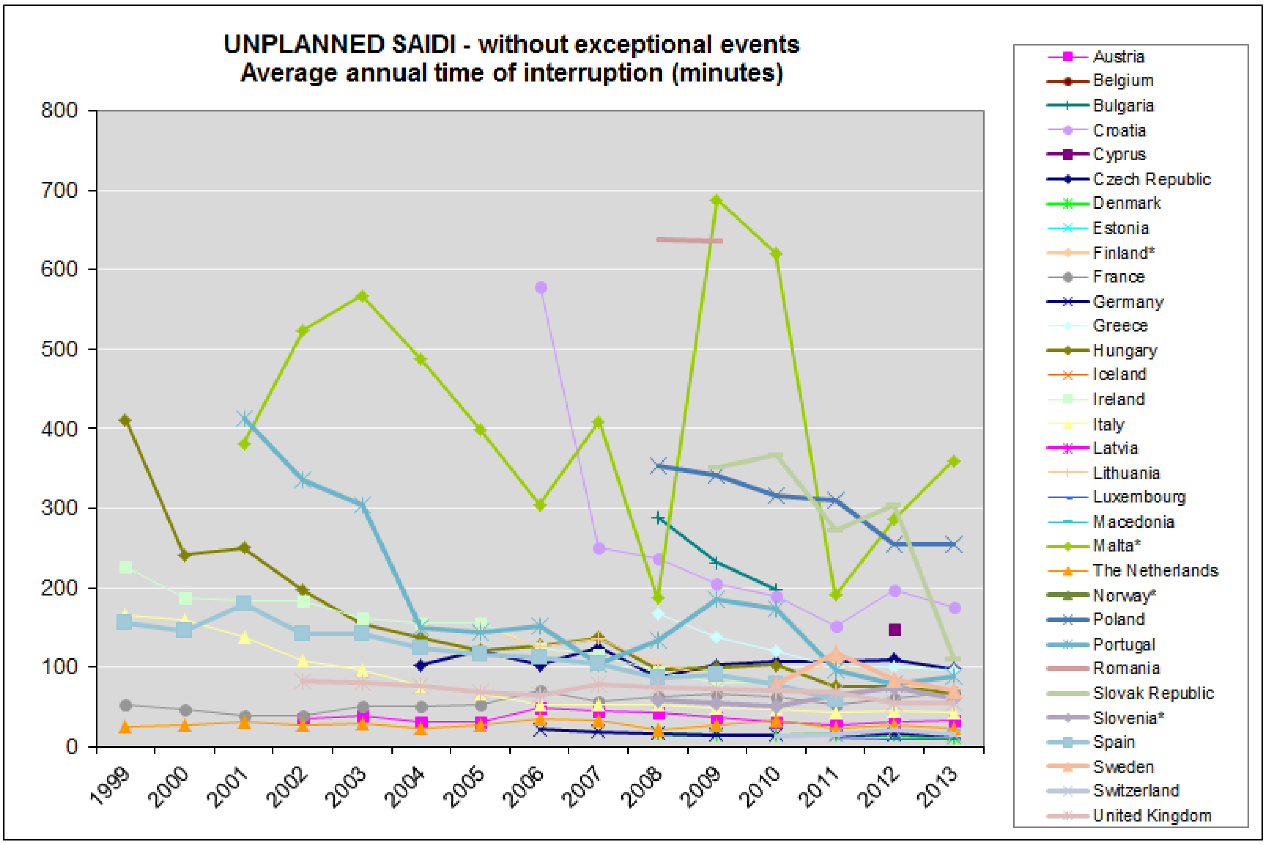

Figure III.1 – Data on power grid availability for European countries (unplanned SAIDI) from [b-CEER]

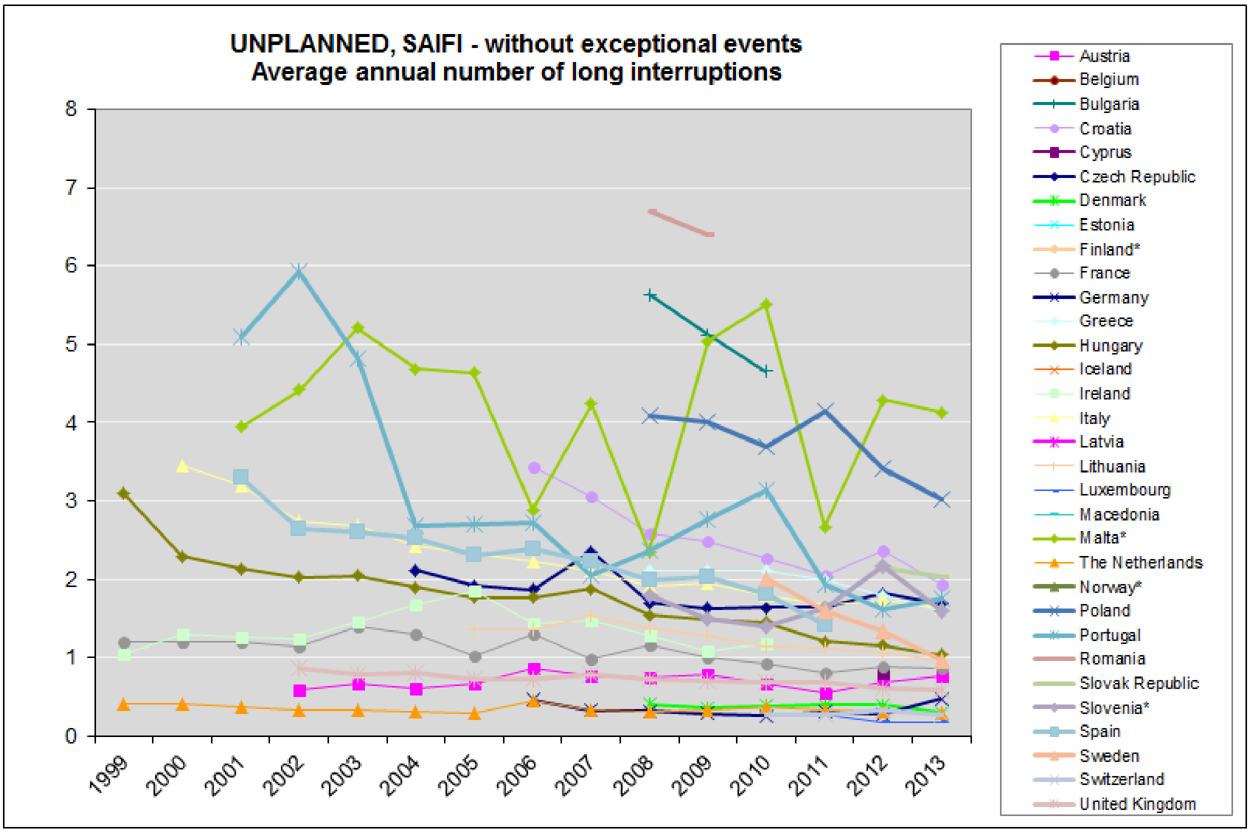

Figure III.2 – Data on power grid availability for European countries (unplanned SAIFI) from [b-CEER]

Figures III.3, III.4 and III.5 give equivalent information for the Italian electrical LV power grid [b-AEEGSI].

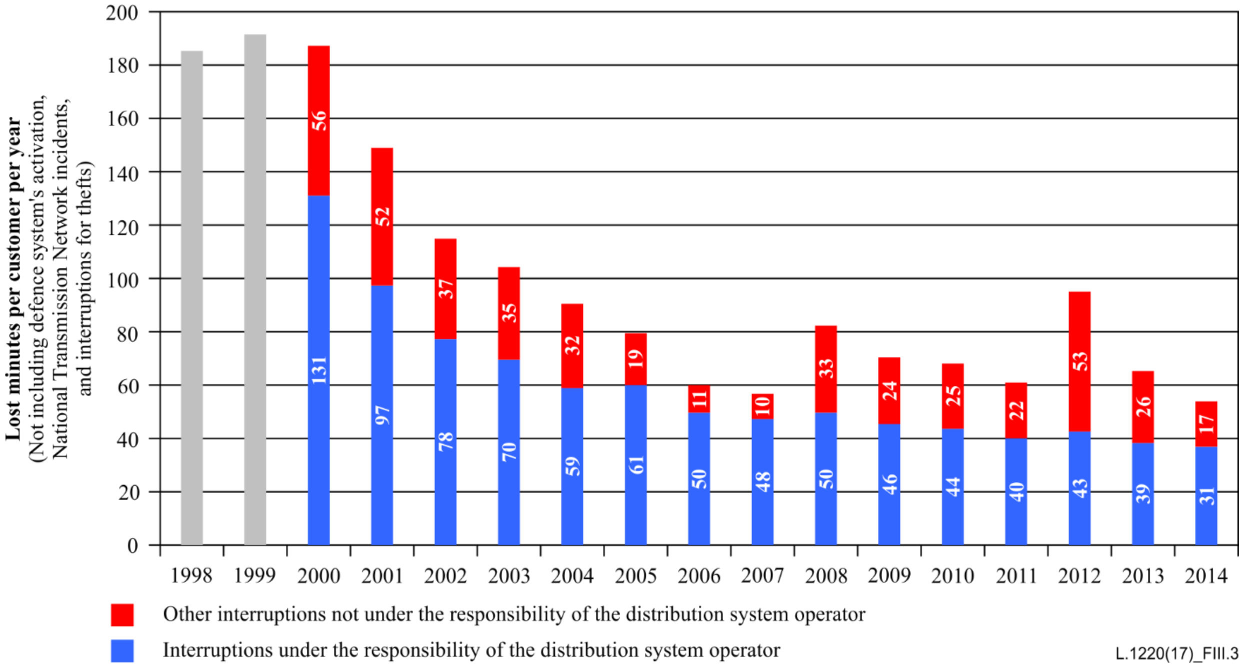

Figure III.3 – Data on power grid availability for Italy (unplanned SAIDI) from [b-CEER]

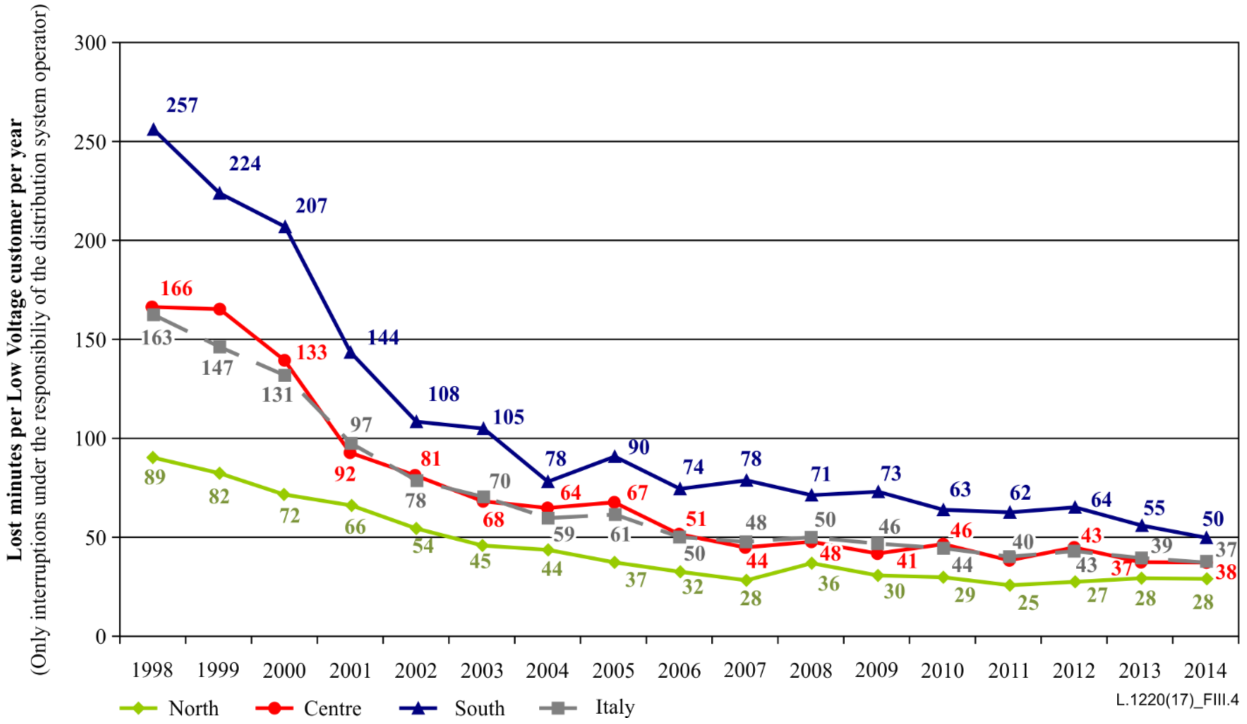

Figure III.4 – Data on power grid availability for Italy
(detail of unplanned SAIDI for north, centre and south Italy) from [b-AEEGSI]

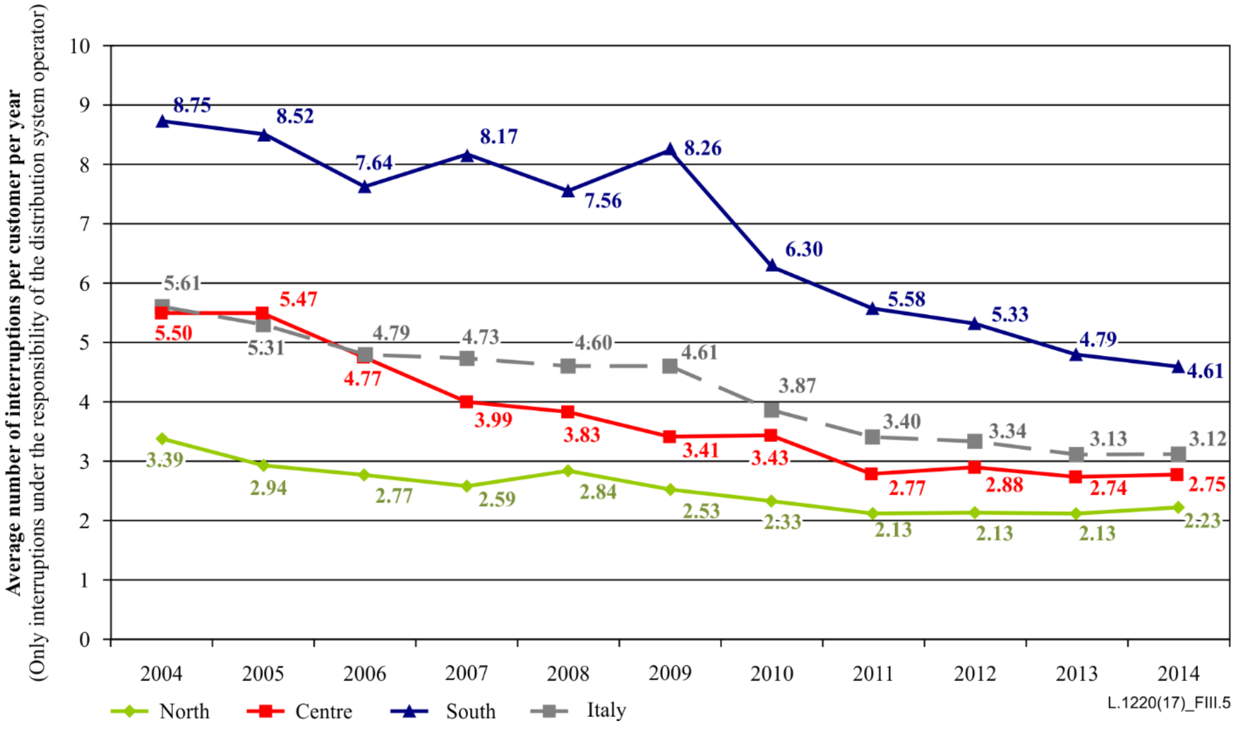

Figure III.5 – Data on power grid availability for Italy
(unplanned SAIFI for north, centre and south area) from [b-AEEGSI]

Figure III.6 shows the comparison of the total unavailability of public switched telephone networks (PSTNs) and of new NGA networks (fibre to the cabinet (FTTCab)) architecture, with or without adoption of mains' micro-interruption coverage – up to 1 s – by supercapacitor 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, a higher availability and reliability, with respect to traditional access network technologies.

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

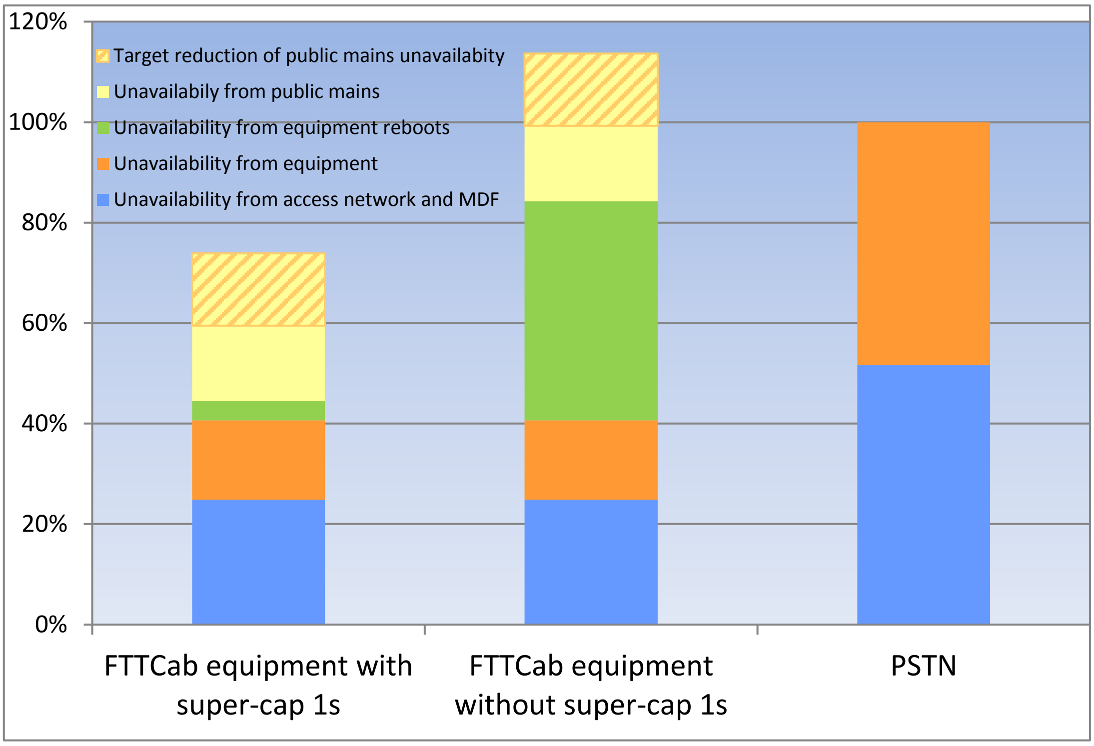

Figure III.6 – Unavailability of new NGA network (FTTCab) vs. classic PSTN

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