BS EN 61427-2:2015

BSI Standards Publication

Secondary cells and batteries for renewable energy storage — General requirements and methods of test

Part 2: On-grid applications

bsi.

National foreword

This British Standard is the UK implementation of EN 61427-2:2015. It is identical to IEC 61427-2:2015. Together with BS EN 61427-1:2013, it supersedes BS EN 61427:2005 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee PEL/21, Secondary cells and batteries.

A list of organizations represented on this committee can be obtained on request to its secretary.

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Wiederaufladbare Zellen und Batterien für die Speicherung erneuerbarer Energien - Allgemeine Anforderungen und Prüfverfahren - Teil 2: Netzgekoppelte Anwendungen
(IEC 61427-2:2015)

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CENELEC

European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

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European foreword

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• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2016-07-02
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In the official version, for Bibliography, the following notes have to be added for the standards indicated:

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CONTENTS

FOREWORD ... 4
1 Scope ... 6
2 Normative references ... 6
3 Terms and definitions ... 6
4 General considerations ... 13
5 General test conditions ... 14
5.1 Accuracy of measuring equipment ... 14
5.1.1 Voltage measurements ... 14
5.1.2 Current measurements ... 14
5.1.3 Temperature measurements ... 14
5.1.4 Time measurements ... 14
5.2 Test object considerations ... 14
5.3 Test object battery selection and size considerations ... 15
5.4 Test plan ... 16
6 Battery endurance ... 20
6.1 General ... 20
6.2 Test for endurance in frequency-regulation service ... 20
6.3 Test for endurance in load-following service ... 25
6.4 Test for endurance in peak-power shaving service ... 28
6.5 Test for endurance in photovoltaic energy storage, time-shift service ... 30
7 Battery properties and electrical performance ... 33
7.1 Declaration of the system properties ... 33
7.2 Determination of energy content at +25 °C ambient temperature ... 36
7.3 Determination of the energy efficiency during endurance tests at +25 °C ambient temperature ... 36
7.4 Determination of the energy efficiency during endurance tests at the minimum and maximum ambient temperature ... 38
7.5 Determination of waste heat generated during endurance tests at the maximum ambient temperature ... 42
7.6 Determination of energy requirements during periods of idle state at +25 °C ambient temperature ... 44
Annex A (informative) Battery-related hazards ... 47
A.1 General ... 47
A.2 Examples ... 47
Bibliography ... 49

Figure 1 – Boundary of the full-sized battery (FSB) ... 15
Figure 2 – Two-step selection process of the test object battery (TOB) ... 16
Figure 3 – Workflow for the determination of endurance properties and electrical performance of the TOB as governed by the sequence of test data generation within 6.2 to 6.5 ... 17
Figure 4 – Sequence of performance tests carried out with TOB 1 within an endurance test 6.x ... 17
Figure 5 – Workflow and decision tree for endurance tests 6.2 through 6.5 ... 19
Figure 6 – Frequency regulation service test routine profile (6.2) – Profile a ... 22
Figure 7 – Frequency regulation service test routine profile (6.2) – Profile b ... 22

Figure 8 – Frequency regulation service test routine profile (6.2) – Profile c 23
Figure 9 – Schematic view of the evolution of battery voltage over time during cycling with constant power discharge and charge pulses 24
Figure 10 – Load-following service test routine profile (6.3) – Profile a 26
Figure 11 – Load-following service test routine profile (6.3) – Profile b 27
Figure 12 – Load-following service test routine profile (6.3) – Profile c 27
Figure 13 – Daily peak-power shaving service test routine profile (6.4) 29
Figure 14 – Daily photovoltaic energy storage time-shift service test routine (6.5) – 3 kW 32
Figure 15 – Daily photovoltaic energy storage time-shift service test routine (6.5) – 30 kW 32
Figure 16 – Schematic view of the location of the two sets of energy values (energy to auxiliaries and energy to and from TOB) to be used for the determination of the energy storage efficiency factor η 37
Figure 17 – Schematic view of the location of the two sets of energy values (energy to auxiliaries and energy to and from battery) to be used for the determination of the amount of waste heat generated 43
Figure 18 – Schematic view of the location of the two sets of energy values (energy to auxiliaries and energy to battery) to be used for the determination of the energy requirements during periods of idle state of the battery 45

Table 1 – Summary of endurance test related electrical property data of the full-sized (FSB) and the test object (TOB) battery 34
Table 2 – Summary of physical dimension data of the full-sized battery (FSB) 35
Table 3 – Summary description of the full-sized battery (FSB) 35
Table 4 – Summary description of the test-object battery (TOB) 35
Table 5 – Summary of the constant power discharge performance of the TOB at an ambient temperature of +25 °C ± 3 K 36
Table 6 – Summary of energy efficiencies determined in endurance tests at an ambient temperature of +25 °C ± 3 K 38
Table 7 – Summary of energy efficiencies determined in endurance cycle tests at the minimum and maximum ambient temperature 40
Table 8 – Parameters to achieve and maintain the target operational state of charge, SoC_{OT}, during tests at the minimum ambient temperature 41
Table 9 – Parameters to achieve and maintain the target operational state of charge, SoC_{OT}, during tests at the maximum ambient temperature 42
Table 10 – Summary of energy released as heat during endurance tests at the maximum ambient temperature 44
Table 11 – Summary of energy required during idle state periods at +25 °C ± 3 K ambient temperature 46
Table A.1 – Non-exhaustive listing of potential battery-related hazards to be taken in consideration in risk assessment activities 47
Table A.2 – Non-exhaustive listing of potential installation-related hazards to be taken in consideration in risk assessment activities 48

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SECONDARY CELLS AND BATTERIES FOR RENEWABLE ENERGY STORAGE – GENERAL REQUIREMENTS AND METHODS OF TEST –

Part 2: On-grid applications

FOREWORD

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International Standard IEC 61427-2 has been prepared by IEC technical committee 21: Secondary cells and batteries.

A list of all parts in the IEC 61427 series, published under the general title *Secondary cells and batteries for renewable energy storage – General requirements and methods of test*, can be found on the IEC website.

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FDIS	Report on voting
21/862/FDIS	21/863/RVD

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

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

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

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

SECONDARY CELLS AND BATTERIES FOR RENEWABLE ENERGY STORAGE – GENERAL REQUIREMENTS AND METHODS OF TEST

Part 2: On-grid applications

1 Scope

This part of IEC 61427 relates to secondary batteries used in on-grid Electrical Energy Storage (EES) applications and provides the associated methods of test for the verification of their endurance, properties and electrical performance in such applications. The test methods are essentially battery chemistry neutral, i.e. applicable to all secondary battery types.

On-grid applications are characterized by the fact that batteries are connected, via power conversion devices, to a regional or nation- or continent-wide electricity grid and act as instantaneous energy sources and sinks to stabilize the grid's performance when randomly major amounts of electrical energy from renewable energy sources are fed into it.

Related power conversion and interface equipment is not covered by this part of IEC 61427.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

None.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
accuracy
<of a measuring instrument>

quality which characterizes the ability of a measuring instrument to provide an indicated value close to a true value of the quantity to be measured

Note 1 to entry: This term is used in the "true" value approach.

Note 2 to entry: Accuracy is better when the indicated value is closer to the corresponding true value.

[SOURCE: IEC 60050-311:2001, 311-06-08]

3.2
accuracy class
category of measuring instruments, all of which are intended to comply with a set of specifications regarding uncertainty

[SOURCE: IEC 60050-311:2001, 311-06-09]

3.3
ambient temperature
average temperature of the air or another medium in the vicinity of the equipment

Note 1 to entry - During the measurement of the ambient temperature the measuring instrument/probe should be shielded from draughts and radiant heating.

[SOURCE: IEC 60050-826:2004, 826-10-03]

3.4
maximum ambient temperature
<for battery operation> highest ambient temperature at which the battery is operable and should perform according to specified requirements

[SOURCE: IEC 60050-426:2008, 426-20-17, modified — In the definition, “trace heating” has been replaced with “battery”.]

3.5
minimum ambient temperature
<for battery operation> lowest ambient temperature at which the battery is operable and should perform according to specified requirements

[SOURCE: IEC 60050-426:2008, 426-20-20, modified — In the definition, “trace heating” has been replaced with “battery”.]

3.6
ampere hour
quantity of electrical charge obtained by integrating the current in amperes with respect to time in hours

Note 1 to entry: The SI unit for electric charge is the coulomb (1 C = 1 As) but in practice it is usually expressed in ampere hours (Ah).

3.7
battery
two or more cells fitted with devices necessary for use, for example case, terminals, marking and protective devices

[SOURCE: IEC 60050-482:2004, 482-01-04, modified — In the definition, “one” has been replaced with “two”.]

3.8
battery management system
BMS
battery management unit
BMU
electronic system associated with a battery which monitors and/or manages its state, calculates secondary data, reports that data and/or controls its environment to influence the battery’s performance and/or service life

Note 1 to entry: The function of the battery management system can be fully or partially assigned to the battery pack and/or to equipment that uses this battery.

Note 2 to entry: A battery management system is also called a "battery management unit" (BMU).

Note 3 to entry: This note applies to the French language only.

Note 4 to entry: This note applies to the French language only.

3.9
idle state
<of a battery system> state of a battery which is fully functional but not actively delivering or absorbing energy

Note 1 to entry: Such a system can deliver and absorb energy on demand with a reaction time as required by the application.

Note 2 to entry: The reaction time can vary from a few milliseconds to a few seconds.

3.10
battery support system
BSS
group of interconnected and interactive parts that perform an essential task as a component of a battery system

Note 1 to entry: Such systems are for example electrolyte storage tanks and circulation pumps, cooling and heating devices, exhaust gas abatement systems, fire extinguishers, spill catchment systems, safety barriers, racks and similar facilities.

Note 2 to entry: This note applies to the French language only.

3.11
capacity
<of cells and batteries> quantity of electric charge which a cell or battery can deliver under specified discharge conditions

Note 1 to entry: The SI unit for electric charge, or quantity of electricity, is the coulomb (1 C = 1 As) but in practice, capacity is usually expressed in ampere hours (Ah).

[SOURCE: IEC 60050-482:2004, 482-03-14, modified — In the definition, “quantity of” has been added.]

3.12
charging
<of a battery> operation during which a secondary battery is supplied with electric energy from an external circuit which results in chemical changes within the cell and thus the storage of energy as chemical energy

Note 1 to entry: A charge operation is defined by its maximum voltage, current, duration and other conditions as specified by the manufacturer.

[SOURCE: IEC 60050-482:2004, 482-05-27, modified — Note 1 to entry has been added.]

3.13
constant power charge
<of a battery> operation in which the charge power input, i.e. the product of charge current and charge voltage, is held constant and where the current and voltage freely adjust according to polarization effects of the battery

3.14
discharge
operation by which a battery delivers, to an external electric circuit and under specified conditions, electric energy produced in the cells

[SOURCE: IEC 60050-482:2004, 482-03-23]

3.15
constant power discharge
<of a battery> operation in which the discharge power output, i.e. the product of discharge current and discharge voltage, is held constant and where the current and voltage freely adjust according to polarization effects of the battery

3.16
electrolyte
substance containing mobile ions that render it ionically conductive

Note 1 to entry: The electrolyte may be a liquid, solid or a gel.

[SOURCE: IEC 60050-482:2004, 482-02-29]

3.17
endurance
<of a battery> numerically defined performance during a given test simulating specified conditions of service

[SOURCE: IEC 60050-482:2004, 482-03-44]

3.18
endurance test
<of a battery> test carried out over a time interval to investigate how the properties are affected by the application of stated stresses and by their time duration or repeated application

[SOURCE: IEC 60050-151:2001, 151-16-22, modified — "<of a battery>" has been added before the definition and "of an item" has been deleted from the definition.]

3.19
energy
<of a battery> energy which a battery delivers under specified conditions

Note 1 to entry: The SI unit for energy is the joule (1 J = 1 Ws) but in practice, energy of a battery is usually expressed in watt hours (Wh) (1 Wh = 3 600 J).

Note 2 to entry: Such energy content is generally determined with a constant power (W) discharge.

Note 3 to entry: k or M are unit prefixes in the metric system denoting multiplication of the unit by one thousand (k) or one million (M).

[SOURCE: IEC 60050-482:2004, 482-03-21, modified —Notes 2 and 3 to entry have been added.]

3.20
actual energy
<of a battery> energy content value, determined experimentally at a defined instant of time with a constant power discharge at a specified rate to a specified final voltage and at a specified temperature

Note 1 to entry: This value is expressed in watt hours (Wh) and varies over the operational cycle or life of the battery.

3.21
final voltage
end-of-discharge voltage
cut-off voltage
end-point-voltage
U_{final}
<of a battery> specified voltage of a battery at which the battery discharge is terminated

[SOURCE: IEC 60050-482:2004, 482-03-30]

3.22
flow cell
secondary cell characterized by the spatial separation of the electrode from the fluid volumes which contain active materials

Note 1 to entry: The fluids, consisting of liquids, solutions, suspensions or gases, flow separately through the electrode spaces.

Note 2 to entry: A flow cell in which one of the active materials is, depending on the state of charge, a solid deposited on one of the electrodes, is called a hybrid flow cell.

3.23
flow battery
two or more flow cells electrically connected in series and including all components for their use as an electrochemical energy storage system

Note 1 to entry: The components can be tanks, pumps, thermal and battery management systems, piping and similar.

3.24
frequency regulation service
<with batteries> regulation mode of the electrical power grid with energy drawn from or supplied to batteries to maintain the system frequency within defined limits

Note 1 to entry: This balancing of the temporal variations of grid frequency occurs typically over time periods of the order of seconds to minutes.

3.25
full charge
<of a battery> state of charge wherein the battery has been completely charged in accordance with the manufacturer's recommended charging conditions.

3.26
full-sized battery
FSB
complete battery that meets the absolute requirements of power capability and energy content, as defined in the respective endurance test clauses

Note 1 to entry: This battery is an assembly of n cells, modules or stacks and is equipped with the relative BMS and BSS as needed.

Note 2 to entry: This note applies to the French language only.

3.27
laboratory test
<of a battery> test made under prescribed and controlled conditions that may or may not simulate field conditions

[SOURCE: IEC 60050-192:2015, 192-09-05]

3.28
load following service
<with batteries> regulation mode of the electrical power grid with energy drawn from or supplied to batteries to compensate for temporary variations in load demand

Note 1 to entry: This balancing of the temporary variations of grid load demand occurs typically over time periods of the order of a few minutes to one hour.

3.29
module
standardized and interchangeable assembly of cells connected in series and/or parallel and associated hardware designed for easy assembly into a commercial battery

3.30
operating voltage range
operating voltage limits
<of a battery> voltage range, as declared by the manufacturer, in which the battery is to be operated and performs according to specifications

3.31
maximum operating voltage
upper voltage limit
U_{max}
<of a battery> upper limit of the voltage range in which the battery is operable and performs according to specifications

3.32
minimum operating voltage
lower voltage limit
U_{min}
<of a battery> lower limit of the voltage range in which the battery is operable and performs according to specification

3.33
peak-power shaving service
load levelling service
<with batteries> process of energy demand management consisting of supplementing the energy in a localized power grid, during periods of excessive demand or instantaneous high electricity costs, with energy drawn from a battery

Note 1 to entry: The energy utilized to “shave off” the demand peak is recharged into the battery in periods of low energy demand or cheap energy supply.

Note 2 to entry: This demand peak-shaving activity lasts typically over time periods of one to several hours.

3.34
PV energy storage time-shift service
<with batteries> process of energy demand management consisting of storing photovoltaic energy in a battery for a time deferred release into a localized power grid

Note 1 to entry: This energy demand management occurs typically with a 24 h day/night rhythm.

3.35
performance
<of a battery> characteristics defining the ability of the battery to achieve the intended function

[SOURCE: IEC 60050-311:2001, 311-06-11, modified — In the definition, “measuring instrument” has been replaced with “battery”.]

3.36
performance test
test carried out to determine the electrical characteristics of a battery

3.37
secondary cell
<electrochemical> basic manufactured unit of an electrochemical system capable of storing electric energy in chemical form and delivering that electrical energy back by reconversion of its stored chemical energy.

[SOURCE: IEC 60050-811:1991, 811-20-01, modified]

3.38
service life
<of a battery> total period of useful life of a cell or battery in operation

Note 1 to entry: For secondary cells and batteries, the service life may be expressed in time, number of charge/discharge cycles, or total throughput in ampere hours (Ah).

[SOURCE: IEC 60050-482:2004, 482-03-46, modified — Note 1 to entry has been deleted.]

3.39
maximum service temperature
maximum operating temperature
maximum permissible temperature
<of a battery> highest temperature which the battery is allowed to attain in normal use as a result of ambient temperatures, induced heat and heat caused by the battery itself

[SOURCE: IEC 60050-442:1998, 442-06-41, modified — In the definition, "connecting device" has been replaced with "battery".]

3.40
minimum service temperature
minimum operating temperature
minimum permissible temperature
<of a battery> lowest temperature which the battery is allowed to attain in normal use as a result of ambient temperatures and forced cooling

3.41
stack
<of a flow battery> two or more flow cells connected in series or in parallel with associated electrical connections and fluid piping

3.42
state of charge
SoC
<of a battery> amount of stored charge in ampere hours (Ah) or energy in watt hours (Wh) related to the actual capacity or energy content

Note 1 to entry: This definition is applicable throughout and only to this part of IEC 61427.

Note 2 to entry: State of charge is expressed as a percentage.

Note 3 to entry: This note applies to the French language only.

3.43
target operational state of charge
SoC_{OT}
<of a battery> pre-defined state of charge to which the energy storage system is driven by a controller or BMS under pre-defined conditions

Note 1 to entry: This SoC_{OT} is to be attained or/and maintained when bidirectional energy transfers to and from the battery are to be achieved within set voltage and SoC limits.

Note 2 to entry: State of charge is expressed as a percentage.

Note 3 to entry: SoC_{OT} is typically the desired or recommended average operating SoC during the specified application scenario. It is selected to improve electrical energy storage (EES) system performance and/or improve the EES system service life in the specified application.

3.44
test
<of a battery> technical operation that consists of the determination of one or more characteristics of a given battery according to a specified procedure

Note 1 to entry: A test is carried out to measure or classify a characteristic of a property of a battery by applying to the battery a set of environmental and operating conditions and/or requirements.

[SOURCE: IEC 60050-151:2001, 151-16-13, modified — In the definition, “product, process or service” has been replaced with “battery”.]

3.45
test object
item submitted to a test, including any accessories, unless otherwise specified

[SOURCE: IEC 60050-151:2001, 151-16-28]

3.46
test object battery
TOB
assembly of $x \times 1/n$ units consisting of cells, modules or stacks of the full-sized battery (FSB), which when assembled in n units, form the FSB which meets the absolute requirements of power capability and energy content as defined in the respective endurance test clauses

Note 1 to entry: The test object battery (TOB) is fully representative of the full-sized battery (FSB) in terms of scalability so that obtained test results can be generalized accurately to the FSB.

Note 2 to entry: The TOB is equipped with the relative BMS and BSS as needed.

Note 3 to entry: This note applies to the French language only.

3.47
time-shift service
<with batteries> process of energy demand management consisting in providing to the grid, at suitable moments, energy stored in batteries at times of ample production or weak demand

Note 1 to entry: This supplying of energy to the grid occurs over time periods typically of the order of a few hours, days or even seasons.

4 General considerations

The supply of energy from renewable energy sources such as wind, solar radiation or tidal forces is characterized by a high degree of intermittency and a low degree of predictability. When their output is fed into the power transmission and distribution grid, overload and instability conditions may develop which make it highly desirable to use rechargeable batteries to temporarily store this energy and then release it in a controlled fashion to smooth and stabilize the flow of power in the grid.

Such instabilities and imbalances in power grids may also result when insufficient power generation capability is present.

The aim of this part of IEC 61427 is to advise and guide future system operators to identify and select suitable rechargeable batteries for grid-connected electrical energy storage (EES). This process will be aided by a set of common test methods that quantify the capability of battery systems of different chemistries and designs in a particular application scenario.

The requirements for battery endurance and electrical performance are linked to the specific EES scenarios to be implemented for the management of excess energy in the grid and the associated capital and operating expenditures for such an installation.

These requirements, expressed as energy efficiency, service life, cumulated energy throughput, installation space and similar, are highly variable since they are eminently application-scenario related and furthermore strongly tied to local costs/benefits and payback time considerations.

Therefore, this part of IEC 61427 does not define these requirements but offers instead test methods to determine and compare the endurance and electrical performance of the candidate storage systems.

All EES batteries have to exhibit safe behaviour. Proper design and associated qualification testing by the battery manufacturers shall ensure this at all levels from the cell to the overall system level.

An informal listing of hazards associated with batteries and battery installations is included in this part of IEC 61427. This list should help in the assessment of the possible reactions of the batteries when they are exposed to abnormal and abusive service conditions.

5 General test conditions

5.1 Accuracy of measuring equipment

5.1.1 Voltage measurements

The instruments used shall be of an accuracy class of at least 0,5 (%) or better.

5.1.2 Current measurements

The instruments used shall be of an accuracy class of at least 0,5 (%) or better.

NOTE Particular attention has to be given to the accuracy of current measurement and current-over-time integration devices as any degraded accuracy or instability can negatively impact the effectiveness of SoC stabilization routines.

5.1.3 Temperature measurements

The instrument used shall have a resolution of 0,5 K. The accuracy of the instrument shall be ±2 K or better.

5.1.4 Time measurements

The instrument used shall have a resolution of 1 s and an accuracy of 0,1 % of the measured time interval.

5.2 Test object considerations

This part of IEC 61427 and the resulting test results are intended to assist the future operator of an electrical energy storage system in the selection of the most suitable battery for the target application by providing comparable data of candidate systems.

The battery system to be tested shall include the cells or modules or stacks and, when they are essential for the operation of the battery, the battery management system (BMS) and battery support systems (BSS).

The boundary of this battery system is outlined by the dotted line in Figure 1.

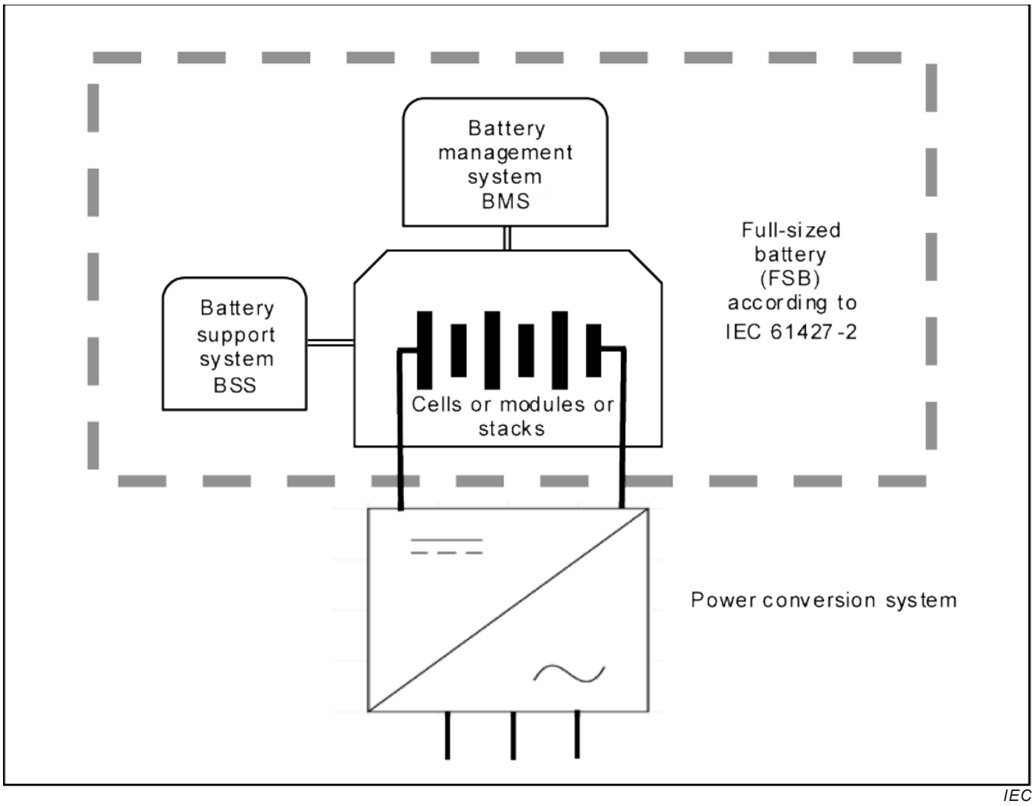


Figure 1 – Boundary of the full-sized battery (FSB)

Power conversion systems and components and associated interfaces are not within the scope of this part of IEC 61427 and are not necessarily present when the tests, according to Clauses 6 and 7, are carried out.

5.3 Test object battery selection and size considerations

The battery systems offered by the manufacturers for on-grid electric energy storage reflect the intrinsic constraints of each cell chemistry and design as well as the specific needs of the target application or service. Such batteries range typically from a few kilowatts to up to 50 MW in power capability and up to 100 MWh in energy content. No common size exemplifying each prospective cell chemistry is yet available.

When the manufacturer or end-user carries out the testing of a battery system to generate data in compliance with this part of IEC 61427, freedom shall be granted to choose that design, model and size which is most suitable for yielding the endurance and electrical performance needed for the selected application or service. These applications or services are exemplified by the endurance tests specified in 6.2 through 6.5. These battery sizes and layouts may vary from one cell chemistry or application to another.

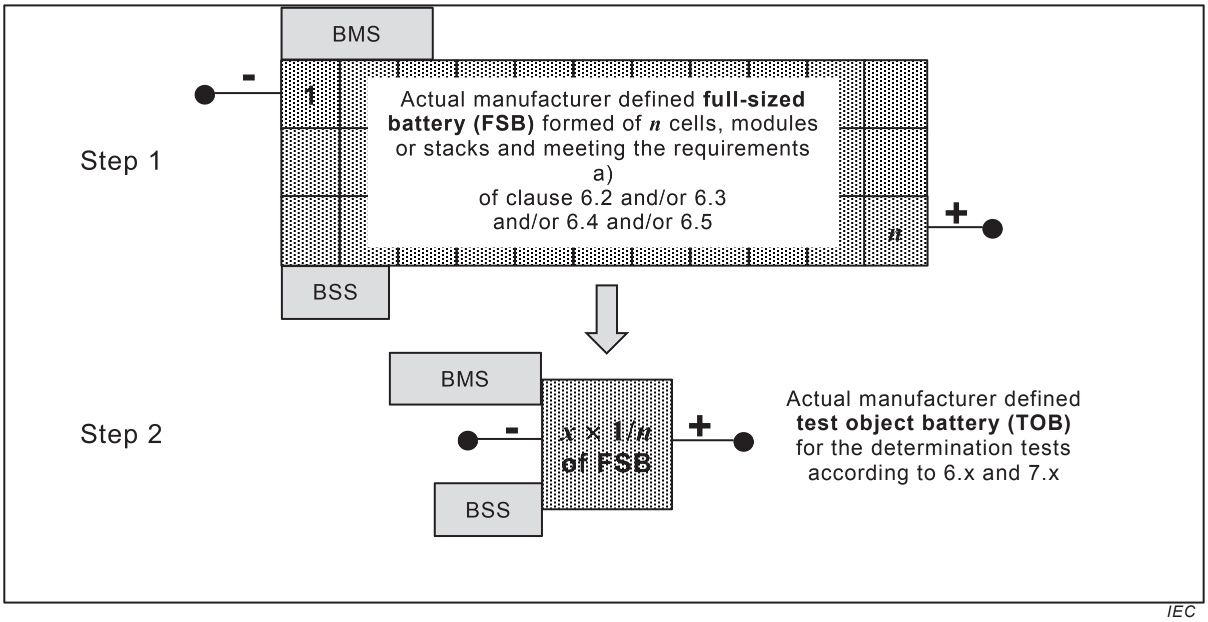


Figure 2 – Two-step selection process of the test object battery (TOB)

In order to assure the generation of comparable test data, the following constraints shall be respected.

- Throughout this part of IEC 61427 the relevant batteries are defined as below.

  Full-sized battery (FSB) – The FSB shall consist of the complete battery that meets the absolute requirements of power capability and energy content as defined in 6.2 or 6.3 or 6.4 or 6.5, as applicable. This battery may be an assembly of n cells, modules or stacks and shall be equipped with the relevant BMS and BSS as needed. Thus up to five different FSBs may be defined.

  Test object battery (TOB) – The TOB and its associated BMS and BSS shall be representative of each of the FSBs above in terms of scalability of endurance and performances so that test results can be extrapolated accurately and hence demonstrate the performance of the FSB. The TOB shall be an assembly of $x \times 1/n$ cells, modules or stacks as present in the above FSB. The minimum number x is defined in the relevant test clause. Unless otherwise specified, all the tests shall be carried out on this TOB.

  The steps to define this TOB are outlined in Figure 2.

- All the TOB's utilized for the verification of the behaviour in the selected application service, as exemplified by test 6.2 or 6.3 or 6.4 or 6.5, shall be of the same size, design and features. No ad-hoc adaptation of the design, just to meet a particular test environment, is permitted.
- Any BMS and BSS essential for the operation of the TOB shall be included.
- Only those endurance tests for which the battery is designed/specified shall be carried out.
- When an available battery-based EES system with different power capability and/or energy content requires testing for compliance with the clauses of this part of IEC 61427, then such a choice is permitted provided that all other provisions are fulfilled and this deviation is stated in the test documentation.

5.4 Test plan

The following provisions apply.

- The tests for the verification of the suitability of a battery, for a particular application scenario, shall be accomplished with not more than two individual and identical TOBs.

- TOB 1 shall be used to carry out the relevant endurance test 6.2 or 6.3 or 6.4 or 6.5 and the associated nested performance tests 7.2 through 7.5. See also Figure 3, Figure 4 and Figure 5.

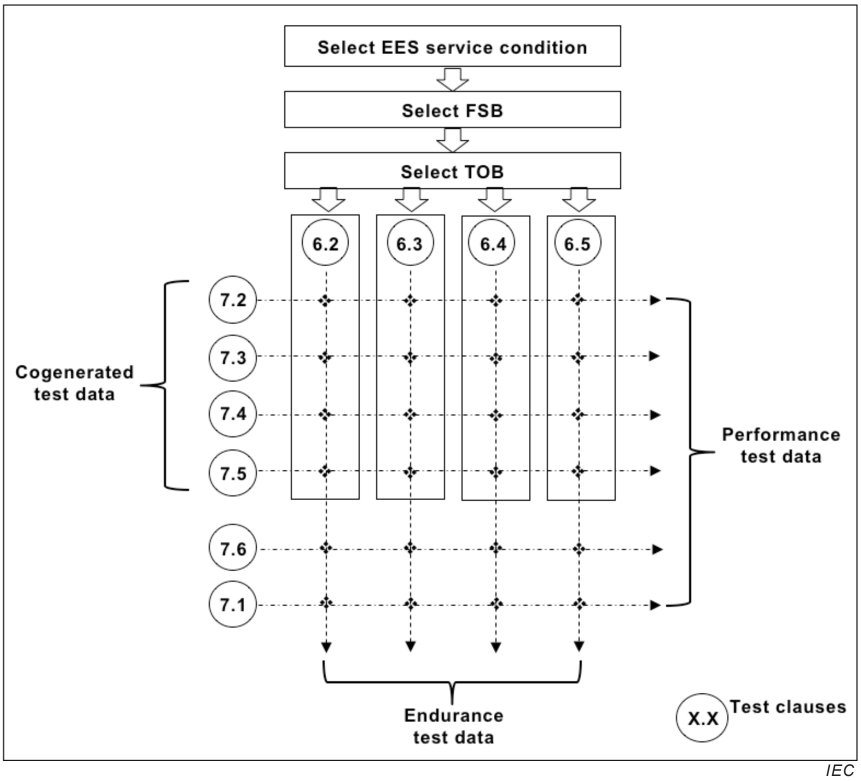
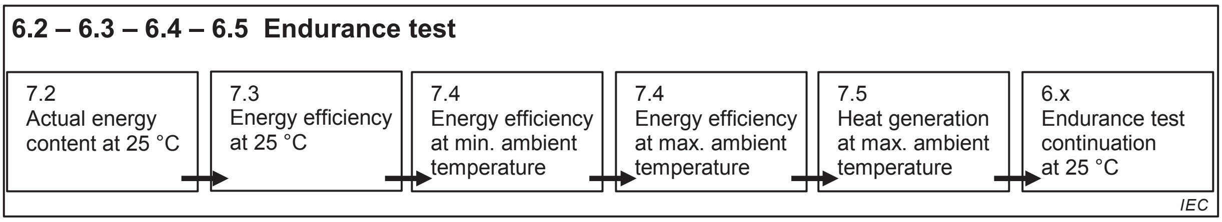


Figure 3 – Workflow for the determination of endurance properties and electrical performance of the TOB as governed by the sequence of test data generation within 6.2 to 6.5



NOTE 1 The details of the performance test are specified in 7.2 through 7.5.

NOTE 2 The performance tests 7.2 to 7.5 are sequential and combined with the relevant endurance test.

NOTE 3 The test profile used in the performance tests 7.3 to 7.5 is that of the relative endurance test.

Figure 4 – Sequence of performance tests carried out with TOB 1 within an endurance test 6.x

- TOB 2 shall be used to carry out the low-stress-level performance test 7.6 (Energy requirement in idle state), which could precede any endurance test allowing ultimately to reduce the number of TOBs, per application scenario verification, to a single TOB. The number of TOBs eventually used shall be reported in Table 1.
- Subclause 7.1 requires the summarizing of data and does not require an additional TOB.
- The test conditions of 7.4, and associated subclause 7.5, keep the TOB within acceptable thermal stress levels at the manufacturer's specified lowest and highest ambient temperatures. At these temperatures the battery is declared operable by the manufacturer

and performs according to specified requirements; thus, no additional TOB is needed for these tests.

- The manufacturer shall carry out only those endurance tests for which the FSB, and by derivation the TOB, has been designed/specified.
- An endurance test can be terminated at any moment when the battery manufacturer has demonstrated the declared service life of the FSB design with a robust extrapolation of the energy acceptance and delivery capability, over time, of the TOB.
- Relevant changes in materials and design of an FSB which impact endurance or performance shall be evaluated for their bearing on the test results in Clauses 6 and 7 by repeating the tests most likely to be impacted by the change.

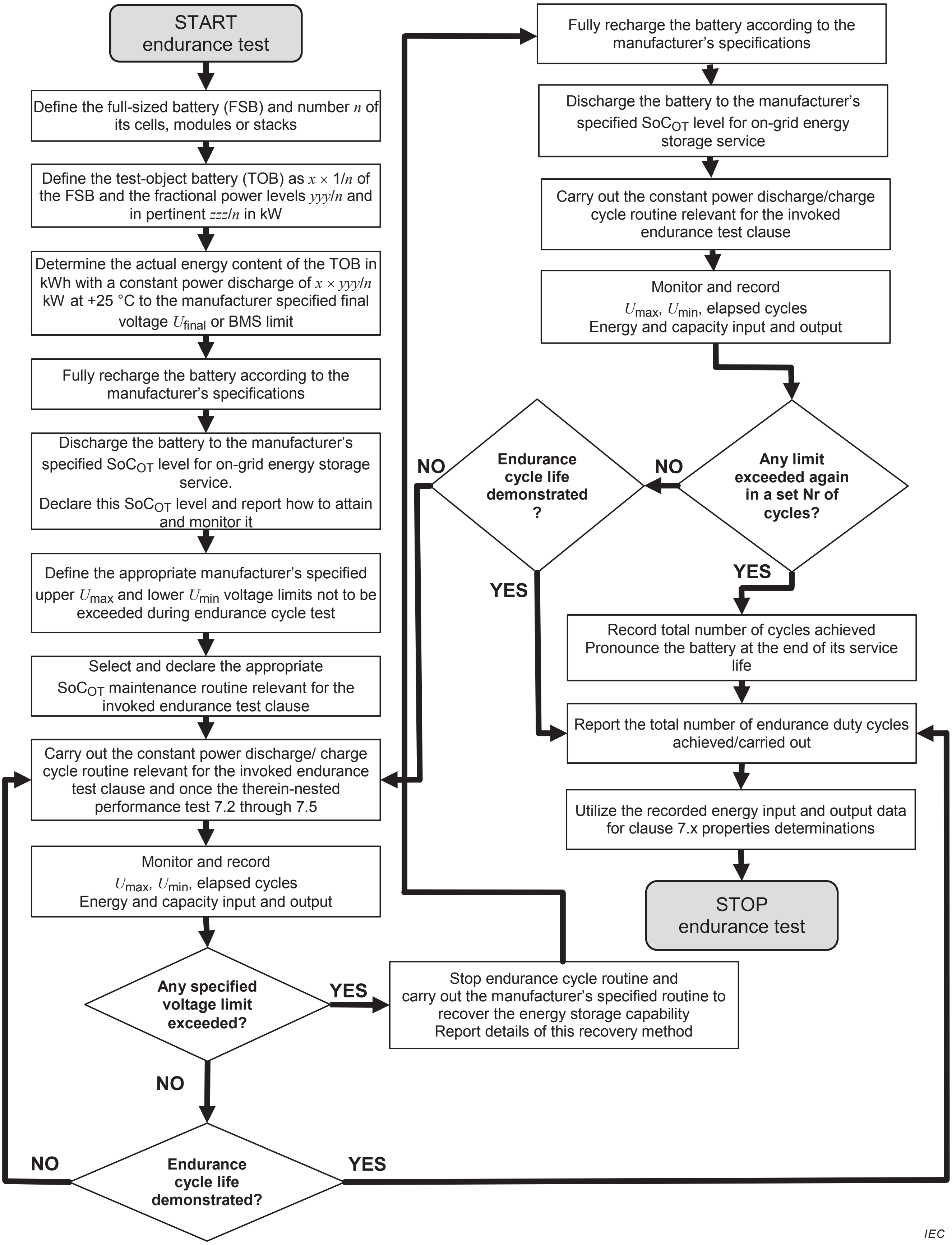


Figure 5 – Workflow and decision tree for endurance tests 6.2 through 6.5

6 Battery endurance

6.1 General

The endurance tests in this part of IEC 61427 are intended to determine the suitability of the battery design to accept and deliver energy under experimental conditions that reproduce in a simplified way the duty the battery will be expected to perform in on-grid energy storage applications.

The key stress factors in such a service are

a) the charge and discharge power levels per available energy content,

b) the operation in a state of charge (SoC) of less than 100 %, and

c) the large number of duty cycles to be accomplished over the service life.

The test conditions are formulated to quantify the battery endurance in the following four application scenarios: frequency-regulation, load-following, peak-power shaving and photovoltaic energy storage time-shift duty.

The highly random energy transfer to and from the battery in on-grid energy storage is simulated with more simplified energy exchange routines.

It is recognized that the individual energy exchange routines chosen may not replicate exactly all the service conditions in the field, which is typical of laboratory tests.

The regular use of these tests, for product development and for qualification purposes, will nevertheless guide the manufacturer and EES system operator in developing and selecting the proper battery.

6.2 Test for endurance in frequency-regulation service

The test conditions are as follows.

a) The manufacturer shall select and define a full-sized battery (FSB) which is able to

   1) supply and accept continued 500 kW and 1 000 kW constant power pulses as per j) within the battery operating voltage limits specified by the manufacturer and when the battery is thermally equilibrated at an ambient temperature of +25 °C, and

   2) tolerate such energy transfers multiple times per hour and 24 h per day without exceeding the manufacturer’s specified operating voltage limits.

b) The manufacturer shall report how many cells, modules or stacks make up such a FSB. This value is termed n.

c) The manufacturer shall define the fraction of power ($500/n$) kW and ($1\ 000/n$) kW such a cell, module or stack will deliver or accept when it is part of the FSB and this battery meets the conditions of 1) to 2) in 6.2 a).

d) The manufacturer shall assemble with x of such cells, modules or stacks the appropriate TOB having at least

   1) four (4) cells in series (only if these cells are commercialized individually),

   or

   2) one or more modules that result in at least four (4) cells in series,

   or

   3) one stack with at least four (4) flow cells in series,

   and incorporate the relevant BMS and BSS peripherals.

e) When a battery based EES system with different power capability and/or energy content requires testing for compliance with this part of IEC 61427, then such choice is acceptable provided that all other provisions are fulfilled and this deviation is stated in the test documentation.

f) The actual energy content E (in kWh) of this TOB, after the manufacturer specified full charge and thermal equilibration in air at +25 °C ± 3 K ambient temperature, shall be determined with a constant power discharge at the ($x \times 500/n$) kW power level to the final voltage U_{final} or to the BMS mandated discharge limit as specified by the manufacturer so as to generate the data as required in 7.2.

g) The TOB shall then be fully recharged according to the manufacturer's specifications.

h) The TOB shall then be discharged to such a target operational state of charge (SoC_{OT}) that it can repetitively deliver and accept the fractional power and energy levels without exceeding the manufacturer's specified operating voltage limits.

i) The manufacturer shall report this target operational state of charge (SoC_{OT}) level, expressed as a percentage of the actual energy content as determined in f), and ways to achieve it in Table 1.

j) The TOB shall then be submitted, at an ambient temperature of +25 °C ± 3 K, to a continuous sequence of discharge/charge pulses defined in 1) through 8) and associated SoC_{OT} adjustment profiles a or b or c. The minimum and maximum battery voltage and the cumulative discharged and charged capacity (in Ah) and energy (in kWh) of the TOB shall be monitored and recorded.

   1) Discharge for 2 min with constant power at the fractional power level of ($x \times 500/n$) in kW.

   2) Discharge for 1 min with constant power at the fractional power level of ($x \times 1\,000/n$) in kW.

   3) Charge for 2 min with constant power at the fractional power level of ($x \times 500/n$) in kW.

   4) Charge for 1 min with constant power at the fractional power level of ($x \times 1\,000/n$) in kW.

   5) Discharge for 1 min with constant power at the fractional power level of ($x \times 1\,000/n$) in kW.

   6) Discharge for 2 min with constant power at the fractional power level of ($x \times 500/n$) in kW.

   7) Charge for 1 min with constant power at the fractional power level of ($x \times 1\,000/n$) in kW.

   8) Charge for

   2 min with constant power at the fractional power level of ($x \times 500/n + a$) in kW where a is the additional power i.e. energy needed to maintain the target operational state of charge SOC_{OT}. The manufacturer shall specify and report the value a in Table 1. The value of ($x \times 500/n + a$) in kW shall be equal to or less than ($x \times 1\,000/n$) in kW (see, for example, Figure 6 – Profile a).

   or

   ($2 + t$) min with constant power at the fractional power level of ($x \times 500/n$) in kW where t is the additional time of charge needed to maintain the target operational state of charge SOC_{OT}. The manufacturer shall specify and report the value t (see, for example, Figure 7 – Profile b) in Table 1.

   or

   2 min with constant power at the fractional power level of ($x \times 500/n$) in kW and every K cycles, i.e. number of completed pulse discharge and charge cycles, 1 through 8, carry out a SoC_{OT} maintenance charge with a power not larger than ($x \times 1\,000/n$) in kW and a duration as specified by the manufacturer. The manufacturer shall specify and report the value K and the power level and duration of this SoC_{OT} maintenance charge (see, for example, Figure 8 – Profile c) in Table 1.

9) Return to 1) and perform 1) to 8) 840 times to sequentially generate the test data according to 7.3 followed by those according to 7.4 and 7.5. See also Figure 4.

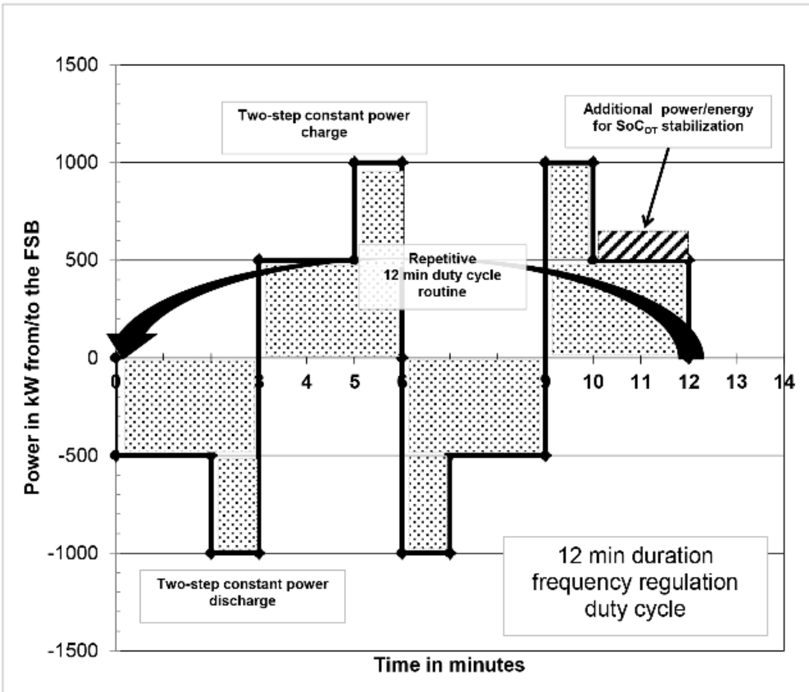


Figure 6 – Frequency regulation service test routine profile (6.2) – Profile a

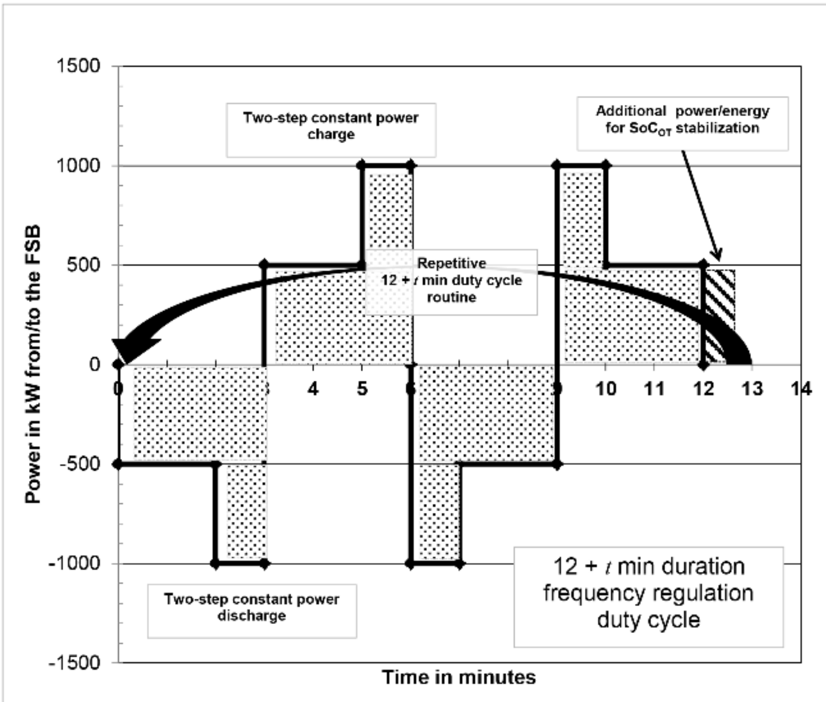


Figure 7 – Frequency regulation service test routine profile (6.2) – Profile b

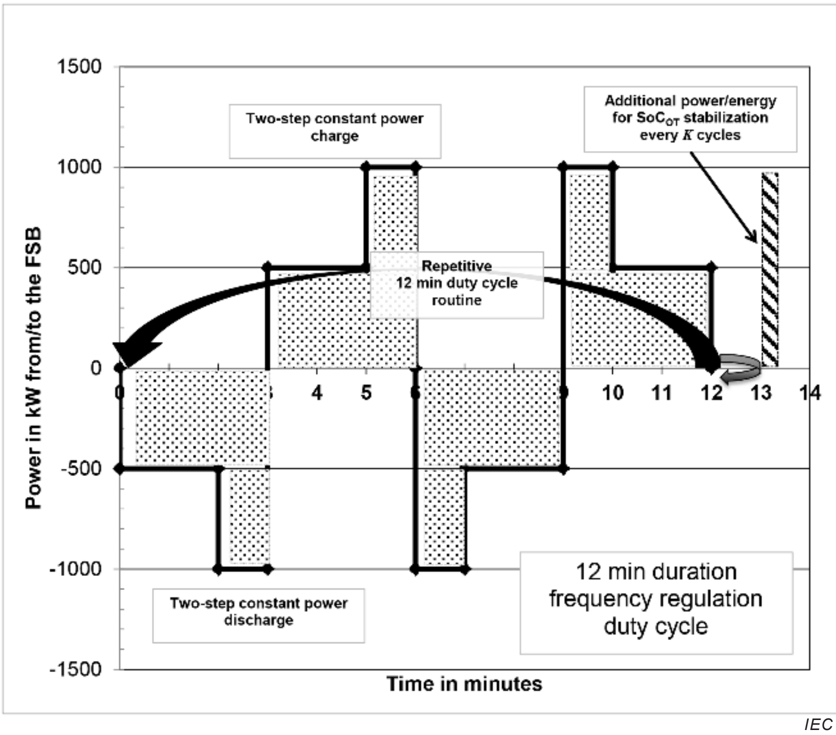


Figure 8 – Frequency regulation service test routine profile (6.2) – Profile c

k) If the TOB voltage in j) exceeds the manufacturer's defined limits of operating voltages then the energy delivery or acceptance capability of the TOB, and by derivation that of the FSB, shall be considered degraded. Figure 9 gives a schematic view of the evolution of battery voltage.

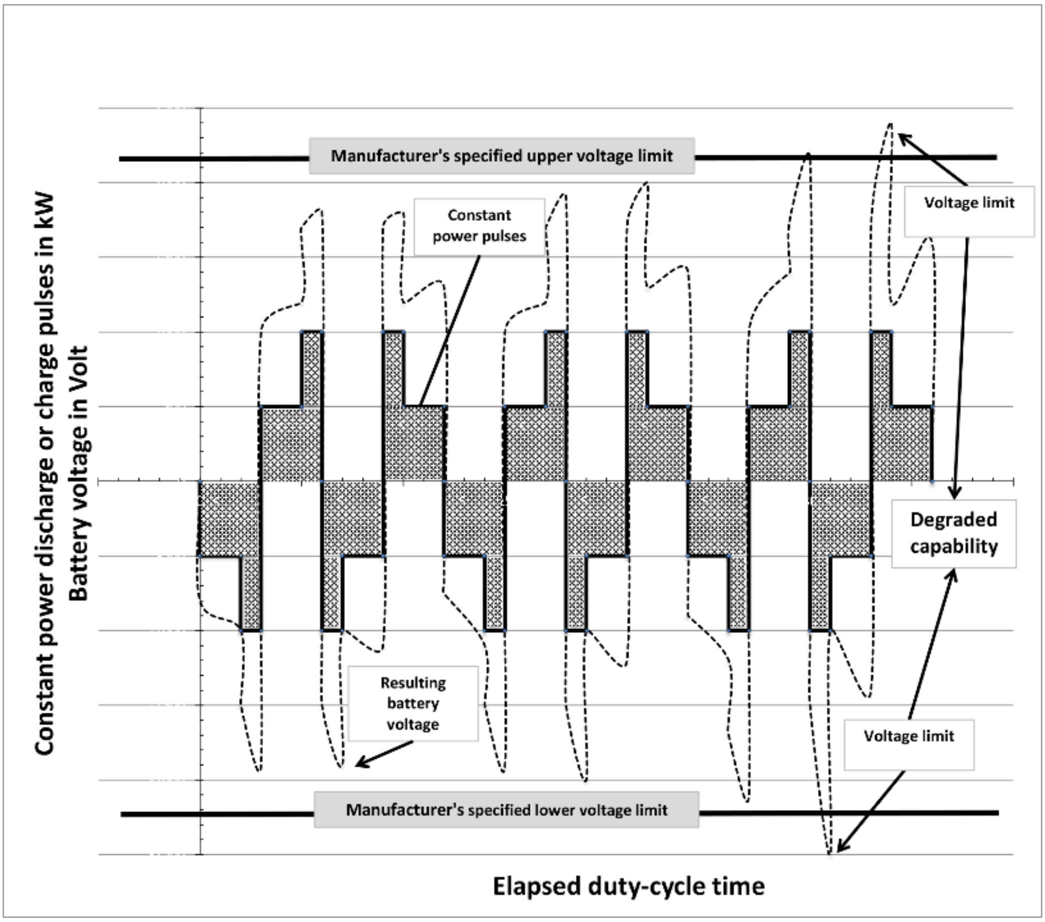


Figure 9 – Schematic view of the evolution of battery voltage over time during cycling with constant power discharge and charge pulses

l) The cycling shall then be stopped and an attempt made to restore the capability of the TOB according to the manufacturer's specification. The details of this operation to recover the energy storage capability shall be reported in Table 1.

m) A new set of operations h) through j) shall then be initiated. If the TOB voltage in j) exceeds the manufacturer's defined operating voltage limits again within 120 sequences j) items 1) to 8) (≈24 h), then the energy delivery or acceptance capability of the TOB, and by derivation that of the FSB, shall be considered irreversibly degraded and the TOB as having reached the end of its service life. Otherwise the cycle sequence specified in sequence j) shall be continued as specified or until the next occurrence of exceeding a limiting value as described in k).

n) The endurance of the TOB, in a particular application scenario, is defined by the total number of completed sequences of j) items 1) to 8) before end-of-service life according to m) is reached.

o) The energy efficiency during these endurance test segments shall be determined according to 7.3 or 7.4 and reported in Table 6 and Table 7, respectively.

p) The heat generation at the maximum ambient temperature during the endurance test segment shall be determined according to 7.5 and reported in Table 10.

q) If in j) the SoC_{OT} maintenance is achieved with the profile c), then the integration duration shall be adapted in such a manner that at least one such SoC_{OT} maintenance charge event c) is included.

r) At the completion of the determination of energy efficiencies and heat generation according to 7.3, 7.4 and 7.5 within the endurance test 6.2, this endurance test shall be resumed at g) and carried out by ignoring section 9) and o), p) and q) until the TOB is declared irreversibly degraded or the battery manufacturer has demonstrated the declared service life of the FSB design with a robust extrapolation of the energy acceptance and delivery capability, over time, of the TOB.

6.3 Test for endurance in load-following service

The test conditions are as follows.

a) The manufacturer shall select and define a full-sized battery (FSB) which is able to
   1) supply and accept continued 180 kW and 360 kW constant power pulses as per j) within the battery operating voltage limits specified by the manufacturer and when the battery is thermally equilibrated at an ambient air temperature of +25 °C, and
   2) tolerate such energy transfers multiple times per hour and 24 h per day without exceeding the manufacturer's specified operating voltage limits.
b) The manufacturer shall report how many cells, modules or stacks make up such a FSB. This value is termed n.
c) The manufacturer shall define the fraction of power ($180/n$) kW and ($360/n$) kW such a cell, module or stack will deliver or accept when it is part of the FSB and this battery meets the conditions of 1) to 2) in 6.3 a).
d) The manufacturer shall assemble with x of such cells, modules or stacks the appropriate TOB having at least
   1) four (4) cells in series (only if these cells are commercialized individually),

   or

   2) one or more modules with at least four (4) cells in series,

   or

   3) one stack with at least four (4) flow cells in series,

   and incorporate the relevant BMS and BSS peripherals.
e) When a battery based EES system with different power capability and/or energy content requires testing for compliance with this part of IEC 61427, then such choice is acceptable provided that all other provisions are fulfilled and this deviation is stated in the test documentation.
f) The actual energy content E (in kWh) of this TOB, after the manufacturer specified full charge and thermal equilibration in air at +25 °C ± 3 K ambient temperature, shall be determined with a constant power discharge at the ($x \times 180/n$) kW power level to the final voltage U_{final} or to the BMS mandated discharge limit as specified by the manufacturer so as to generate the data as required in 7.2.
g) The TOB shall then be fully recharged according to the manufacturer's specifications.
h) The TOB shall then be discharged to such a target operational state of charge (SoC_{OT}) that it can repetitively deliver and accept the fractional power and energy levels without exceeding the manufacturer's specified operating voltage limits.
i) The manufacturer shall report this target operational state of charge (SoC_{OT}) level, expressed as percentage of the actual energy content as determined in f), and ways to achieve it in Table 1.
j) The TOB battery shall then be submitted, at an ambient temperature of +25°C ±3K, to a continuous sequence of discharge/charge pulses defined in 1) through 8) and associated SoC_{OT} adjustment profiles a or b or c. The minimum and maximum battery voltage and the cumulative discharged and charged capacity (in Ah) and energy (in kWh) of the TOB shall be monitored and recorded.
   1) Discharge for 8 min with constant power at the fractional power level of ($x \times 180/n$) in kW.
   2) Discharge for 4 min with constant power at the fractional power level of ($x \times 360/n$) in kW.

3) Charge for 8 min with constant power at the fractional power level of ($x \times 180/n$) in kW.
4) Charge for 4 min with constant power at the fractional power level of ($x \times 360/n$) in kW.
5) Discharge for 4 min with constant power at the fractional power level of ($x \times 360/n$) in kW.
6) Discharge for 8 min with constant power at the fractional power level of ($x \times 180/n$) in kW.
7) Charge for 4 min with constant power at the fractional power level of ($x \times 360/n$) in kW.
8) Charge for

   8 min with constant power at the fractional power level of ($x \times 180/n + a$) in kW where a is the additional power, i.e. energy needed to maintain the target operational state of charge (SoC_{OT}). The manufacturer shall specify and report the value a in Table 1. The value of ($x \times 180/n + a$) in kW shall be equal to or less than ($x \times 360/n$) in kW (see, for example, Figure 10 – Profile a).

   or

   ($8 + t$) min with constant power at the fractional power level of ($x \times 180/n$) in kW where t is the additional time of charge needed to maintain the target operational state of charge (SoC_{OT}). The manufacturer shall specify and report the value t (see, for example, Figure 11 – Profile b) in Table 1.

   or

   8 min with constant power at the fractional power level of ($x \times 180/n$) in kW and every K cycles, i.e. number of completed pulse discharge and charge cycles 1) through 8), carry out a SoC_{OT} maintenance charge with a power not larger than ($360/n$) in kW and a duration as specified by the manufacturer. The manufacturer shall specify and report the value K and the power level and duration of this SoC_{OT} maintenance charge (see, for example, Figure 12 – Profile c) in Table 1.
9) Return to 1) and perform 1) to 8) 210 times to sequentially generate the test data according to 7.3 followed by those according to 7.4 and 7.5. See also Figure 4.

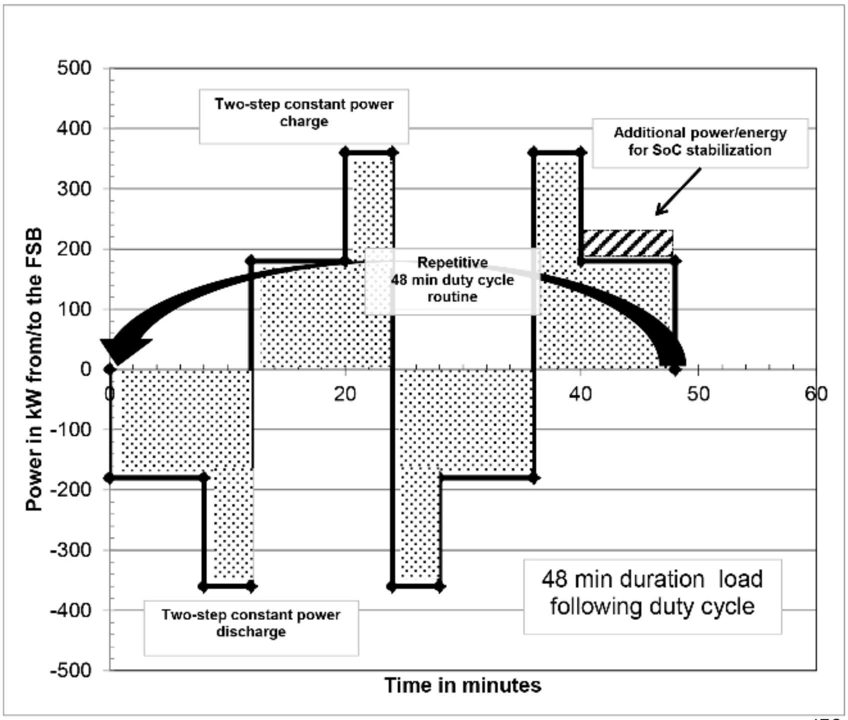


Figure 10 – Load-following service test routine profile (6.3) – Profile a

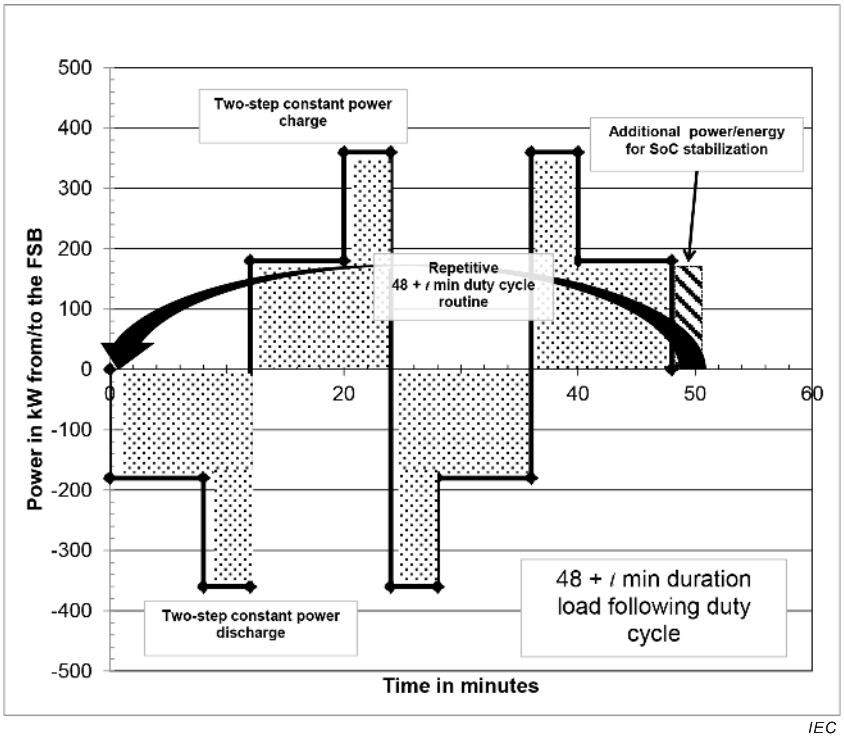


Figure 11 – Load-following service test routine profile (6.3) – Profile b

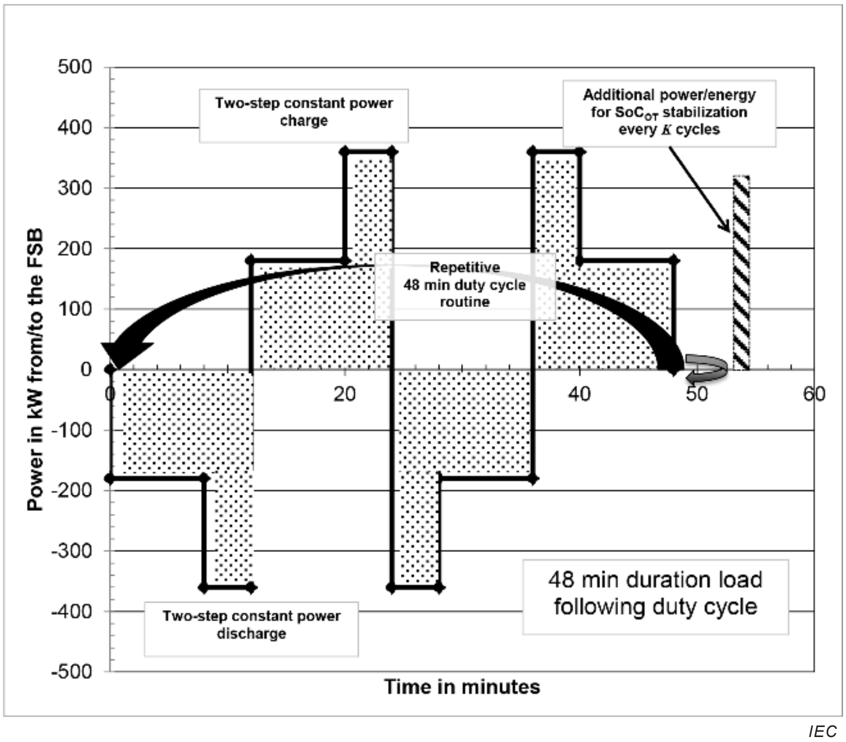


Figure 12 – Load-following service test routine profile (6.3) – Profile c

k) If the TOB voltage in j) exceeds the manufacturer's defined limits of operating voltages, then the energy delivery or acceptance capability of the TOB, and by derivation that of the FSB, shall be considered degraded.

l) The cycling shall then be stopped and an attempt made to restore the capability of the TOB according to the manufacturer's specification. The details of this operation to recover the energy storage capability shall be reported in Table 1.

m) A new set of operations h) through j) shall then be initiated. If the test TOB voltage in j) exceeds the manufacturer's defined operating voltage limits again within 60 sequences j) items 1) to 8) (≈ 48 h), then the energy delivery or acceptance capability of the TOB, and by derivation that of the FSB, shall be considered irreversibly degraded and the TOB as having reached the end of its service life. Otherwise the cycle sequence specified in sequence j) shall be continued until the next occurrence of exceeding a limiting value as described in k).

n) The endurance of the TOB, in a particular application scenario, is defined by the total number of completed sequences of j) items 1) to 8) before end-of-service life according to m) is reached.

o) The energy efficiency during these endurance test segments shall be determined according to the provisions of 7.3 or 7.4 and reported in Table 6 and Table 7, respectively.

p) The heat generation at the maximum ambient temperature during the endurance test segment shall be determined according to 7.5 and reported in Table 10.

q) If in j) the SoC_{OT} maintenance is achieved with the profile c), then the integration duration shall be adapted in such a manner that at least one such SoC_{OT} maintenance charge event c) is included.

r) At the completion of the determination of energy efficiencies and heat generation according to 7.3, 7.4 and 7.5 within the endurance test 6.3, this endurance test shall be resumed at g) and carried out by ignoring section 9) and o), p) and q) until the TOB is declared irreversibly degraded or the battery manufacturer has demonstrated the declared service life of the FSB design with a robust extrapolation of the energy acceptance and delivery capability, over time, of the TOB.

6.4 Test for endurance in peak-power shaving service

The test conditions are as follows.

a) The manufacturer shall select and define a full-sized battery (FSB) which is able to
   1) supply multiple 500 kW constant power discharge pulses as per 6.4 i) within the battery operating voltage limits specified by the manufacturer and when the battery is thermally equilibrated at an ambient air temperature of +25 °C, and
   2) tolerate such energy transfers every day without exceeding the manufacturer's specified operating voltage limits.

b) The manufacturer shall report how many cells, modules or stacks make up such a FSB. This value is termed n.

c) The manufacturer shall define the fraction of power ($500/n$) kW such a cell, module or stack will deliver or accept when it is part of the FSB and this battery meets the conditions of 1) to 2) in 6.4 a).

d) The manufacturer shall assemble with x of such cells, modules or stacks the appropriate TOB having at least
   1) four (4) cells in series (only if these cells are commercialized individually),

   or

   2) one or more modules with at least four (4) single cells in series,

   or

   3) one stack with at least four (4) flow cells in series,

   and incorporate the relevant BMS and BSS peripherals.

e) When a battery based EES system with different power capability and/or energy content requires testing for compliance with this part of IEC 61427, then such a choice is acceptable provided that all other provisions are fulfilled and this deviation is stated in the test documentation.

f) The actual energy content E (in kWh) of this TOB, after the manufacturer specified full charge and thermal equilibration in air at +25 °C ± 3 K ambient temperature, shall be determined with a constant power discharge at the ($x \times 500/n$) kW power level to the final voltage U_{final} or to the BMS mandated discharge limit as specified by the manufacturer so as to generate the data as required in 7.2.

g) The TOB shall then be fully recharged according to the manufacturer's specifications.

h) The manufacturer shall report the target operational state of charge (SoC_{OT}) level and ways to achieve it in Table 1.

i) The TOB battery shall then be submitted, at an ambient temperature of +25 °C ± 3 K, to a sequence of discharge/open-circuit/charge events defined in 1) through 5) without exceeding the manufacturer's specified operating voltage limits. The minimum and maximum battery voltage and the cumulative discharged and charged capacity (in Ah) and energy (in kWh) of the TOB shall be monitored and recorded.

1) Discharge for 180 min with constant power at the fractional power level of ($x \times 500/n$) in kW (example of morning peak-power shaving activity). The test profile is as shown, for example, in Figure 13.

2) Do not deliver energy for 180 min.

   If the BMS or BSS is powered directly by the battery then the battery can supply this energy also during the "off-power" period of step 2 and step 4. This amount of energy shall be taken into account in the efficiency calculation as below (7.3 and 7.4).

3) Discharge for 180 min with constant power at the fractional power level of ($x \times 500/n$) in kW (example of afternoon peak power shaving activity).

4) Do not deliver energy for 60 min.

5) Charge for not more than 840 min with a fractional power level not greater than ($x \times 500/n$) in kW, maximum voltage and total energy input as specified by the manufacturer. After not more than 840 min the battery shall have reached again a SoC_{OT} as specified by the manufacturer. The recharge parameters shall be reported in Table 1.

6) Return to 1) and perform 1) to 5) seven times to sequentially generate the test data according to 7.3 followed by those according to 7.4 and 7.5. See also Figure 4.

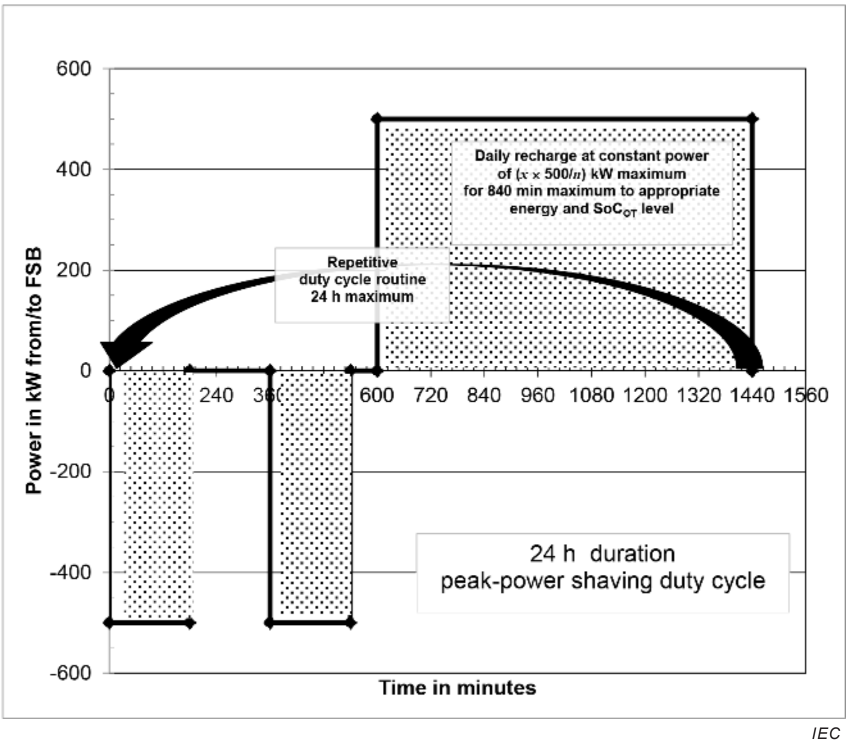


Figure 13 – Daily peak-power shaving service test routine profile (6.4)

j) If the TOB voltage in i) exceeds the manufacturer's defined limits of operating voltages then the energy delivery or acceptance capability of TOB, and by derivation that of the FSB, shall be considered degraded.

k) The cycling shall then be stopped and an attempt made to restore the capability of the TOB according to the manufacturer's specification. The details of this operation to recover the energy storage capability shall be reported in Table 1.

l) A new set of operations g) through i) shall then be initiated. If the test object battery TOB voltage in i) exceeds the manufacturer's defined operating voltage limits again within seven sequences i) items 1) to 5) (≈ 1 week), then the energy delivery capability of the TOB, and by derivation that of the FSB, shall be considered irreversibly degraded and the TOB as having reached the end of its service life. Otherwise the cycle sequence described in sequence i) shall be continued until the next occurrence of exceeding a limiting value as described in i).

m) The endurance of the TOB, in a particular application scenario, is defined by the total number of completed sequences of i) items 1) to 5) before end-of-service life according to l) is reached.

n) The energy efficiency during these endurance test segments shall be determined according to 7.3 and 7.4 and reported in Table 6 and Table 7 respectively.

o) The heat generation at the maximum ambient temperature during the endurance test segment shall be determined according to 7.5 and reported in Table 10.

p) At the completion of the determination of energy efficiencies and heat generation according to 7.3, 7.4 and 7.5 within the endurance test 6.4, this endurance test shall be resumed at g) and carried out by ignoring section 6) and n) and o) until the TOB is declared irreversibly degraded or the battery manufacturer has demonstrated the declared service life of the FSB design with a robust extrapolation of the energy acceptance and delivery capability, over time, of the TOB.

6.5 Test for endurance in photovoltaic energy storage, time-shift service

The test conditions are as follows:

a) The manufacturer shall select and define a full-sized battery (FSB) which is able to

   1) accept daily photovoltaic energy at a constant power level of either 3 kW and 1,5 kW or 30 kW and 15 kW as per j) within the battery operating voltage limits specified by the manufacturer and when the battery is thermally equilibrated at an ambient air temperature of +25 °C,

   2) deliver the stored photovoltaic energy at power levels of 3 kW or 30 kW, and

   3) tolerate such energy transfers every day without exceeding the manufacturer's specified operating voltage limits.

b) The manufacturer shall report how many cells, modules or stacks make up such a FSB. This value is termed n.

c) The manufacturer shall define the fraction of power ($3/n$) kW or ($30/n$) kW such a cell, module or stack will accept and deliver when it is part of the FSB and this battery meets the conditions of 1) to 3) in 6.5 a).

d) The manufacturer shall assemble with x of such cells, modules or stacks the appropriate TOB having at least

   1) four (4) cells in series (only if these cells are commercialized individually),

   or

   2) one or more modules with at least four (4) cells in series,

   or

   3) one stack with at least four (4) flow cells in series,

   and incorporate the relevant BMS and BSS peripherals.

e) When a battery based EES system with different power capabilities and/or energy content requires testing for compliance with this part of IEC 61427, then such a choice is acceptable provided that all other provisions are fulfilled and this deviation is stated in the test documentation.

f) The actual energy content E (in kWh) of this TOB, after the manufacturer specified full charge and thermal equilibration in air at +25 °C ± 3 K ambient temperature, shall be determined with a constant power discharge at the ($x \times 3/n$) or ($x \times 30/n$) kW power level to the final voltage U_{final} or to the BMS mandated discharge limit as specified by the manufacturer so as to generate the data as required in 7.2.

g) The TOB shall then be fully recharged according to the manufacturer's specifications.

h) The TOB shall then be discharged to such a target operational state of charge (SoC_{OT}) so that it can accept the fractional power and energy levels without exceeding the manufacturer's specified operating voltage limits.

i) The manufacturer shall report this target operational state of charge (SoC_{OT}) level and ways to achieve it in Table 1.

j) The TOB battery shall then be submitted, at an ambient temperature of +25 °C ±3 K, to a sequence of discharge/open-circuit/charge events defined in 1) through 5). The minimum and maximum battery voltage and the cumulative discharged and charged capacity (in Ah) and energy (in kWh) of the TOB shall be monitored and recorded.

   1) Charge for 240 min with constant power at the fractional power level of ($x \times 3/n$) or ($x \times 30/n$) kW (photovoltaic energy storage activity). The test profile is as shown, for example, in Figure 14 and Figure 15.

   2) Charge for 120 min with constant power at the fractional power level of 0,5($x \times 3/n$) or 0,5($x \times 30/n$) kW *(*photovoltaic energy storage activity).

   3) Do not receive or deliver power for 60 min.

   NOTE The two-step constant power PV energy storage profile reflects in part the somewhat bell-shaped profile of the energy output of solar cells during the day.

   If the BMS or BSS is powered directly by the battery then this energy can be supplied by the battery also during the "off-power" period of step 3. This amount of energy shall be taken in account in the efficiency calculation as below (7.3 and 7.4).

   4) Discharge with constant power at the fractional power level of ($x \times 3/n$) or ($x \times 30/n$) kW (stored photovoltaic energy use activity) until the manufacturer specified final voltage (U_{final}), SoC_{OT} (%) or discharged energy (kWh) or capacity (Ah) level is reached and the battery can again accept, during the next daylight period, PV energy for the duration and power levels defined in 1) and 2) above. The discharge parameters shall be reported in Table 1.

   5) At the termination of the discharge as per 4), do not receive or deliver power for the remaining time to 1 440 min (24 h) elapsed cycle time.

   6) Return to 1) and perform 1) to 5) seven times to sequentially generate the test data according to 7.3 followed by those according to 7.4 and 7.5. See also Figure 4.

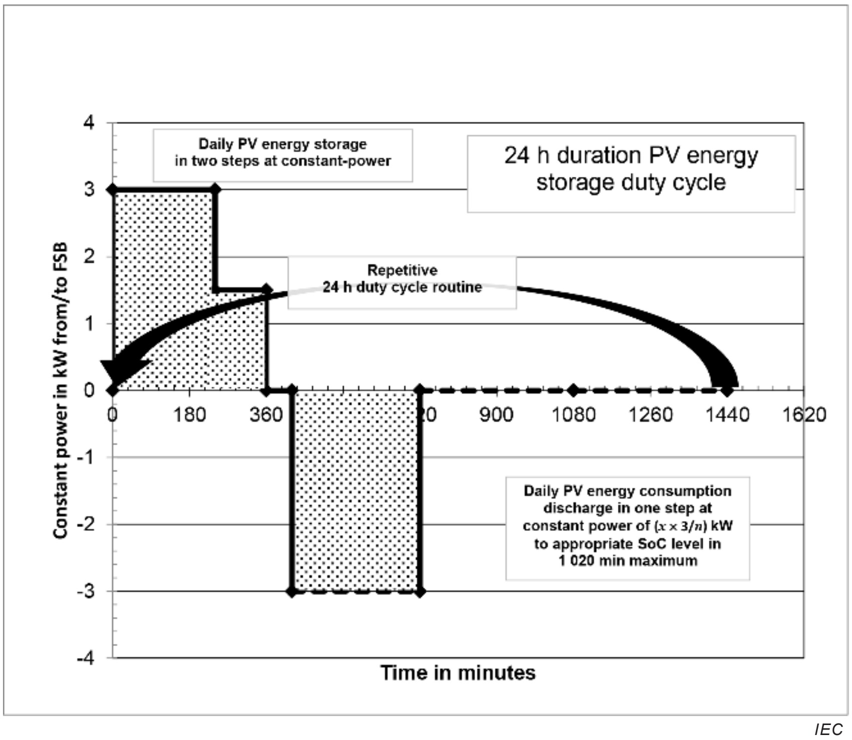


Figure 14 – Daily photovoltaic energy storage time-shift service test routine (6.5) – 3 kW

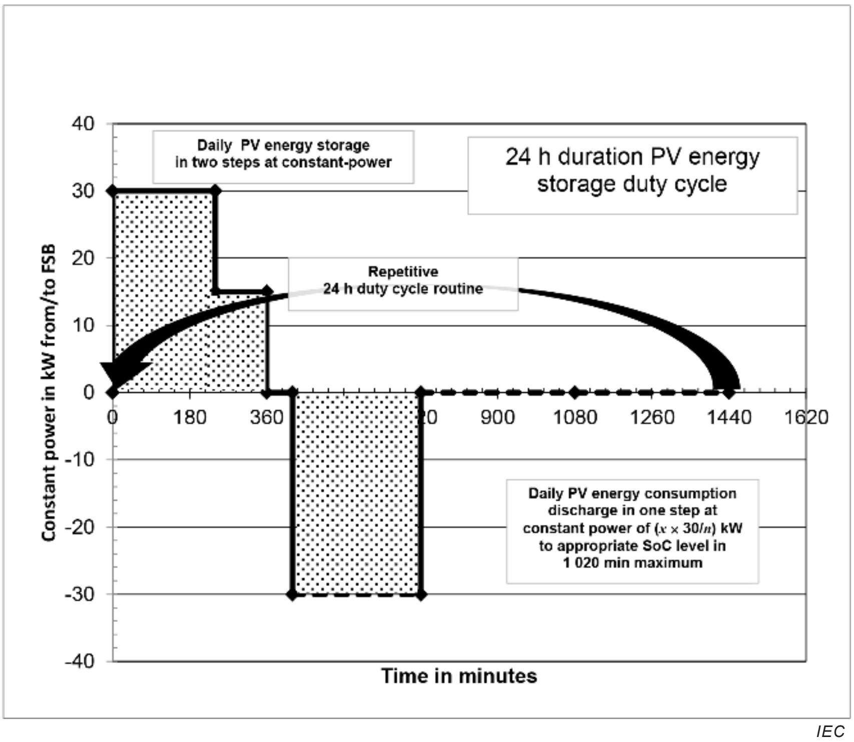


Figure 15 – Daily photovoltaic energy storage time-shift service test routine (6.5) – 30 kW

k) If the TOB cannot accept the specified energy at the power level defined in j) without exceeding the manufacturer’s defined operating voltage limits, then the energy storage capability of the TOB, and by derivation that of the FSB, shall be considered degraded.

l) The cycling shall then be stopped and an attempt made to restore the capability of the TOB according to the manufacturer's specification. The details of this operation to recover the energy storage capability shall be reported in Table 1.

m) A new set of operations j) shall then be initiated. If the test TOB voltage in j) exceeds the manufacturer's defined operating voltage limits again within seven sequences j) items 1) to 5) (1 week), then the energy acceptance capability of the TOB, and by derivation that of the FSB, shall be considered irreversibly degraded and the battery as having reached the end of its service life. Otherwise the cycle sequence described in sequence j) shall be continued until the next occurrence of exceeding a limiting value as described in k).

n) The endurance of the TOB, in a particular application scenario, is defined by the total number of completed sequences of j) items 1) to 5) before end-of-service life according to m) is reached.

o) The energy efficiency during these endurance test segments shall be determined according to 7.3 or 7.4 and reported in Table 6 and Table 7, respectively.

p) The heat generation at the maximum ambient temperature during the endurance test segment shall be determined according to 7.5 and reported in Table 10.

q) At the completion of the determination of energy efficiencies and heat generation according to 7.3, 7.4 and 7.5 within the endurance test 6.5, this endurance test shall be resumed at g) and carried out ignoring section 6) and o) and p) until the TOB is declared irreversibly degraded or the battery manufacturer has demonstrated the declared service life of the FSG designs with a robust extrapolation of the energy acceptance and delivery capability, over time, of the TOB.

7 Battery properties and electrical performance

7.1 Declaration of the system properties

The key features of the full-sized battery (FSB) and test object battery (TOB) of 6.2 through 6.5, as available from the manufacturer or determined experimentally, shall be reported in Tables 1, 2, 3 and 4 with appropriate accuracy.

Table 1 – Summary of endurance test related electrical property data of the full-sized (FSB) and the test object (TOB) battery

Properties	Unit	Battery of subclause				
		6.2	**6.3**	**6.4**	**6.5**	**6.5**
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Declared energy content E in kWh of the FSB at the indicated power level	kW	500	180	500	3	30
	kWh					
FSB formed of n cells, modules or stacks	n					
TOB formed of ($x \times 1/n$) cells, modules or stacks	x					
Manufacturer's specified method to achieve full charge of the TOB	n/a	Describe	Describe	Describe	Describe	Describe
Minimum (U_{min}) and maximum (U_{max}) operating voltage of TOB	V_{min}					
	V_{max}					
Fractional discharge power level in $x \times$ kW/n and actual energy content E in kWh of the TOB when discharged according to subclauses 6.x item f) and 7.2 at +25 °C ± 3 K ambient temperature to U_{final} or to the BMS mandated discharge limit	kW					
	kWh					
	V					
	BMS Yes No					
Total number of endurance sequences i) or j) achieved with the TOB until the end-of-life limit of item l) or m) in subclauses 6.x was reached	No.					
Target operational state of charge level (SoC_{OT}) of TOB as a percentage of the actual energy content E and ways to achieve it in the endurance test of 6.2, 6.3 and 6.5	%			n/a		
	kW					
	V					
	min					
Manufacturer recommended SoC_{OT} maintenance procedure for the TOB used in 6.2 j) 8) and 6.3 j) 8) (Values a or t or K, kW, kWh and time) Profile a, b or c	kW			n/a	n/a	n/a
	kWh					
	min					
	No.					
	Profile					
Peak-power shaving duty 6.4 i) recharge parameters of the TOB as specified by the manufacturer (Values of SoC_{OT}, kW, time, V)	%	n/a	n/a		n/a	n/a
	kW					
	min					
	V					
PV energy storage time-shift duty 6.5 j) 4) discharge parameters of the TOB as specified by the manufacturer (Values of SoC_{OT}, kW, time, V)	%	n/a	n/a	n/a		
	kW					
	min					
	V					
Method to recover the energy storage capability of the TOB as used in 6.x l) or k) and as specified by the manufacturer	kW					
	V					
	min					

Properties	Unit	Battery of subclause				
		6.2	6.3	6.4	6.5	6.5
Endurance and performance tests carried were carried out on *n* number of TOB's	No.					
TOB operated with a dedicated BMS and/or BSS	Yes No					

Table 2 – Summary of physical dimension data of the full-sized battery (FSB)

Properties	Unit	Battery of subclause				
		6.2	6.3	6.4	6.5	6.5
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Battery (FSB) – operated with a dedicated BMS and/or BSS	Yes No					
Battery (FSB) – projected footprint with BMS and BSS installed	m^2					
Battery (FSB) – weight with BMS and BSS installed	kg					
Battery (FSB) – height with BMS and BSS installed	m					

Table 3 – Summary description of the full-sized battery (FSB)

Properties	Unit	Battery of subclause				
		6.2	6.3	6.4	6.5	6.5
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Battery chemistry	n/a					
Brand or model name	n/a					
Type designation	n/a					
Manufacturer	n/a					
Hardware and software version	n/a					
Any other useful information	n/a					

Table 4 – Summary description of the test-object battery (TOB)

The required description shall allow understanding of the test object battery (TOB) by listing and illustrating its design features and characteristics so as to be able to extrapolate its performance to that of the full-sized battery (FSB).	
TOB of 6.2	*(Description) (Add pages)*
TOB of 6.3	*(Description) (Add pages)*
TOB of 6.4	*(Description) (Add pages)*
TOB of 6.5 3 kW	*(Description) (Add pages)*
TOB of 6.5 30 kW	*(Description) (Add pages)*

7.2 Determination of energy content at +25 °C ambient temperature

The discharge performance data of the TOB thermally equilibrated at +25 °C ± 3 K ambient temperature shall be determined and reported. These data shall be cogenerated during the execution of the endurance tests of 6.2 through 6.5 and item f).

The test shall be carried out with a TOB and its subsystems of the size identified in 5.3 and the data reported in Table 5.

Table 5 – Summary of the constant power discharge performance of the TOB at an ambient temperature of +25 °C ± 3 K

Properties	Unit	Battery of subclause				
		6.2	6.3	6.4	6.5	6.5
Declared discharge power capability of the full-sized battery (FSB)	kW	500	180	500	3	30
Fractional discharge power level $x \times$ kW/n and actual energy content E in kWh of the TOB when discharged at +25 °C ± 3 K ambient temperature to U_{final} or BMS mandated (Yes/No) discharge termination	kW					
	kWh					
	V					
	Yes No					
TOB open-circuit voltage at +25 °C ± 3 K ambient temperature and fully-charged prior to the discharge with constant power	V					
TOB final discharge voltage (U_{final})	V					
TOB voltage after 10 % of the duration of the constant power discharge	V					
TOB voltage after 50 % of the duration of the constant power discharge	V					
Current after 10 % of the duration of the constant power discharge	A					
Current at U_{final} or at the BMS mandated discharge termination	A					
Total duration of the constant power discharge to U_{final} or to the BMS mandated discharge termination	min					
Actual energy E discharged from the TOB	kWh					
Actual capacity discharged from the TOB during the determination of energy content E	Ah					

7.3 Determination of the energy efficiency during endurance tests at +25 °C ambient temperature

The energy storage efficiency of the TOB shall be determined at +25 °C ± 3 K ambient temperature and reported. These data shall be cogenerated during the execution of the endurance tests of 6.2 through 6.5 starting with item g) and over 840, 210, 7 and 7 repetitions of sequence i) (6.4) or j) (6.2, 6.3 and 6.5), respectively.

The test shall be carried out with a TOB and its subsystems of the size identified in 5.3 and as shown schematically in Figure 16.

The energy storage efficiency factor η is defined as the ratio between net energy discharged (i.e. the difference of discharged energy and the auxiliary (BMS/BSS) energy consumption during the discharge phase) and the total charged energy (i.e. the sum of the charged energy and the auxiliary (BMS/BSS) energy consumption during the charge phase) according to the formula

$$\eta = \frac{E_{\text{out}}}{E_{\text{in}}} = \frac{E_{\text{discharge}} - E_{\text{aux,discharge}}}{E_{\text{charge}} + E_{\text{aux,charge}}}$$

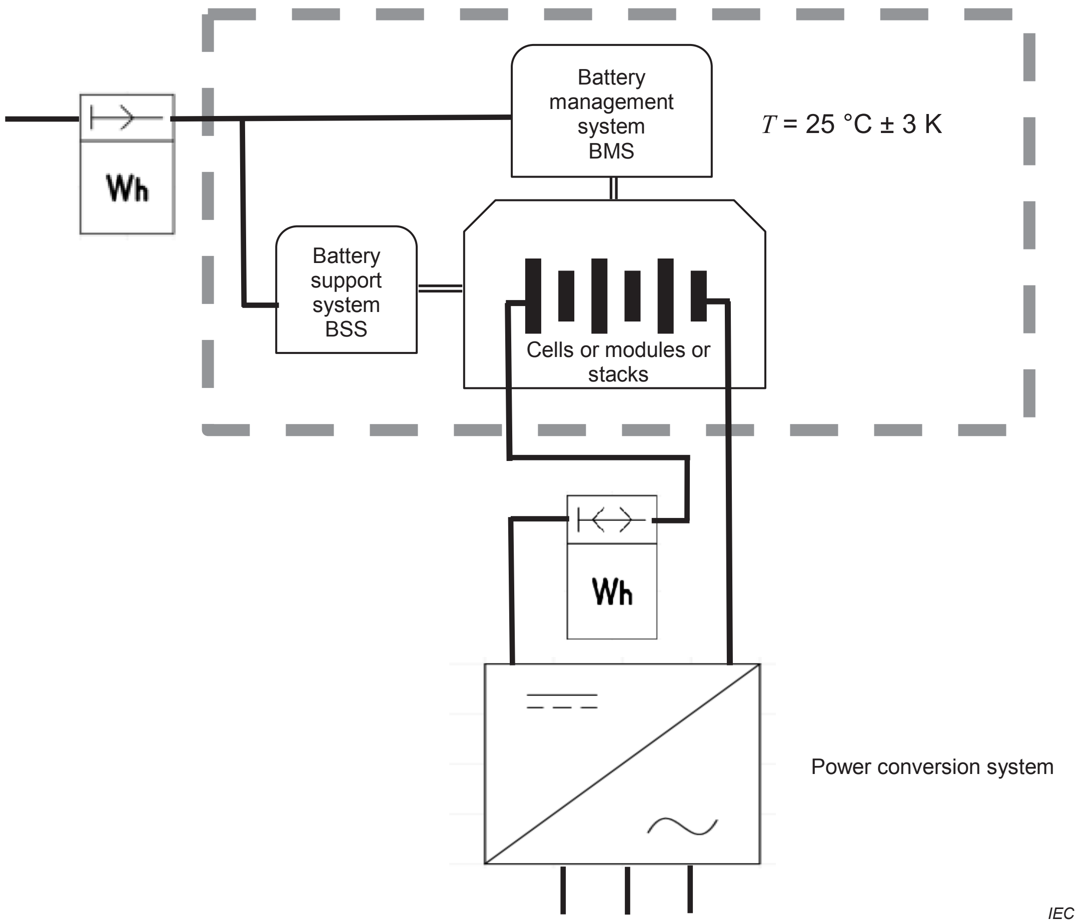


Figure 16 – Schematic view of the location of the two sets of energy values (energy to auxiliaries and energy to and from TOB) to be used for the determination of the energy storage efficiency factor η

This value shall be calculated, from the gathered data, at the beginning and advantageously also toward the end of the endurance test, to track efficiencies during the course of the endurance test and reported in Table 6.

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

Properties	Unit	Battery of subclause				
		6.2	6.3	6.4	6.5	6.5
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Number of endurance test sequences i) or j) over which the energy efficiency factor η is to be determined according to 6.2, 6.3, 6.4, 6.5	No.	840	210	7	7	7
Actual number of endurance test sequences i) or j) over which the energy efficiency factor η has been determined	No.					
Energy consumed by the BMS and BSS of the TOB during the reported number of endurance test sequences i) or j) at +25 °C ± 3 K ambient temperature	kWh					
Energy charged into the TOB during the reported number of endurance test sequences i) or j) at +25 °C ± 3 K ambient temperature	kWh					
Energy discharged from the TOB during the reported number of endurance test sequences i) or j) at +25 °C ± 3 K ambient temperature	kWh					
Energy efficiency factor η at the beginning of the endurance test $\eta = \frac{E_{out}}{E_{in}} = \frac{E_{discharge} - E_{aux,discharge}}{E_{charge} + E_{aux,charge}}$	n/a					
Energy efficiency factor η at the end of the endurance test $\eta = \frac{E_{out}}{E_{in}} = \frac{E_{discharge} - E_{aux,discharge}}{E_{charge} + E_{aux,charge}}$	n/a					

NOTE The energy efficiencies are tied to the intrinsic electrochemical reaction efficiencies during discharge and charge, the energy consumed by the auxiliaries and the charging strategy used to maintain the required SoC_{OT} of the battery.

7.4 Determination of the energy efficiency during endurance tests at the minimum and maximum ambient temperature

The energy storage efficiency of the TOB shall be determined at the manufacturer specified minimum and maximum ambient temperature at which the battery is operable and performs according to specified requirements. These data shall be cogenerated during the execution of the endurance tests of 6.2 through 6.5 starting with item g) and over 840, 210, 7 and 7 repetitions of sequence i) (6.4) or j) (6.2, 6.3 and 6.5), respectively.

The test shall be carried out with a TOB and its subsystems of the size identified in 5.3 and the data reported in Table 7.

a) Prior to the test, the TOB, including any external electrolyte volumes, shall be kept for 24 ± 1 h at the manufacturer's specified minimum ambient temperature within a range of ± 3 K. This may be achieved by placing the TOB into a temperature-controlled cabinet with forced airflow or other equivalent means.

If the temperature limits differ between that admissible during charge or discharge, then a unique value suitable for both conditions may be chosen.

b) While still in the cabinet, the TOB shall, starting with item g) of the endurance test subclause, be submitted to a number of endurance test sequences i) or j) as specified below:

   Subclause 6.2 = 840, Subclause 6.3 = 210, Subclause 6.4 = 7, Subclause 6.5 = 7

c) During the execution of test sequences i) or j), the SoC_{OT} stabilization conditions of profile a, b or c shall be adapted, according to the manufacturer's specifications, in such a way that the required SoC_{OT} level is also reached/maintained at this low ambient temperature. These conditions shall be reported in Table 8.

d) At the conclusion of the low-temperature cycle test, the TOB shall be fully charged according to the manufacturer's specifications.

e) Prior to the test, the TOB, including any external electrolyte volumes, shall then be kept for 24 ± 1 h at the manufacturer's specified maximum ambient temperature within a range of ± 3 K. This may be achieved by placing the TOB into a temperature-controlled cabinet with forced airflow or other equivalent means.

f) While still in the cabinet, the TOB, starting with item g) of the endurance test clause, shall be submitted to a number of endurance test sequences i) or j) as specified below:

   Subclause 6.2 = 840, Subclause 6.3 = 210, Subclause 6.4 = 7, Subclause 6.5 = 7

g) During the execution of test sequences i) or j), the SoC_{OT} stabilization conditions of profile a, b or c shall be adapted, according to the manufacturer's specifications, in such a way that the required SoC_{OT} level is also reached/maintained at this high ambient temperature. These conditions shall be reported in Table 9.

h) The energy storage efficiency factor η shall be determined with the formula

$$\eta = \frac{E_{\text{out}}}{E_{\text{in}}} = \frac{E_{\text{discharge}} - E_{\text{aux,discharge}}}{E_{\text{charge}} + E_{\text{aux,charge}}}$$

   for each of the two temperatures during the relevant and applicable endurance tests and reported in Table 7.

Table 7 – Summary of energy efficiencies determined in endurance cycle tests at the minimum and maximum ambient temperature

Properties	Unit	Battery of subclause				
		6.2	6.3	6.4	6.5	6.5
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Number of endurance test sequences i) or j) over which the energy efficiency factor η is to be determined according to 6.2, 6.3, 6.4, 6.5	No.	840	210	7	7	7
Actual number of endurance test sequences i) or j) over which the energy efficiency factor η has been determined	No.					
Energy consumed by the BMS and BSS of the TOB during the reported number of endurance sequences i) or j) at minimum and maximum ambient temperature	kWh					
	$°C_{min}$					
	kWh					
	$°C_{max}$					
Energy charged into the TOB during the reported number of endurance sequences i) or j) at minimum and maximum ambient temperature	kWh					
	$°C_{min}$					
	kWh					
	$°C_{max}$					
Energy discharged from the TOB during the reported number of endurance sequences i) or j) at minimum and maximum ambient temperature	kWh					
	$°C_{min}$					
	kWh					
	$°C_{max}$					
Energy efficiency factor η at minimum ambient temperature $\eta = \frac{E_{out}}{E_{in}} = \frac{E_{discharge} - E_{aux,discharge}}{E_{charge} + E_{aux,charge}}$	n/a					
Energy efficiency factor η at maximum ambient temperature $\eta = \frac{E_{out}}{E_{in}} = \frac{E_{discharge} - E_{aux,discharge}}{E_{charge} + E_{aux,charge}}$	n/a					

Table 8 – Parameters to achieve and maintain the target operational state of charge, SoC_{OT}, during tests at the minimum ambient temperature

Properties	Unit	Battery of subclause				
		6.2	**6.3**	**6.4**	**6.5**	**6.5**
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Minimum (U_{min}) and maximum (U_{max}) operating voltage of TOB at minimum ambient temperature	x					
SoC_{OT} of TOB as a percentage of the actual energy content E and ways to achieve it in the endurance test of 6.2, 6.3 and 6.5 at minimum ambient temperature	%			n/a		
	kW					
	V					
	min					
Manufacturer recommended SoC_{OT} maintenance procedure for the TOB used in 6.2 j) 8) and 6.3 j) 8) Values a or t or K, kW and time) Profile a, b or c	kW			n/a	n/a	n/a
	kWh					
	min					
	No.					
	Profile					
Peak-power shaving duty 6.4 item i) 5) recharge parameters of the TOB as specified by the manufacturer (Values of SoC_{OT}, kW, time, V) at minimum ambient temperature	%	n/a	n/a		n/a	n/a
	kW					
	min					
	V					
PV energy storage time-shift duty 6.5 j) 4) discharge parameters of the TOB as specified by the manufacturer (Values of SoC_{OT}, kW, time, V) at minimum ambient temperature	%	n/a	n/a	n/a		
	kW					
	min					
	V					
Method to recover the energy storage capability of the TOB used in 6.x l) or k) and as specified by the manufacturer at minimum ambient temperature	kW					
	V					
	min					
TOB operated with a dedicated BMS and/or BSS	Yes No					

Table 9 – Parameters to achieve and maintain the target operational state of charge, SoC_{OT}, during tests at the maximum ambient temperature

Properties	Unit	Battery of subclause				
		6.2	**6.3**	**6.4**	**6.5**	**6.5**
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Minimum (U_{min}) and maximum (U_{max}) operating voltage of TOB at maximum ambient temperature	x					
SoC_{OT}) of TOB as a percentage of the actual energy content E and ways to achieve it in the endurance test of 6.2, 6.3 and 6.5 at maximum ambient temperature	%			n/a		
	kW					
	V					
	min					
Manufacturer recommended SoC_{OT} maintenance procedure for the TOB used in 6.2 j) 8) and 6.3 j) 8) Values a or t or K, kW and time) Profile a, b or c	kW			n/a	n/a	n/a
	kWh					
	min					
	No.					
	Profile					
Peak-power shaving duty 6.4 i) 5) recharge parameters of the TOB as specified by the manufacturer (Values of SoC_{OT}, kW, time, V) at maximum ambient temperature	%	n/a	n/a		n/a	n/a
	kW					
	min					
	V					
PV energy storage time-shift duty 6.5 j) 4) discharge parameters of the TOB as specified by the manufacturer (Values of SoC_{OT}, kW, time, V) at maximum ambient temperature	%	n/a	n/a	n/a		
	kW					
	min					
	V					
Method to recover the energy storage capability of the TOB used in 6.x l) or k) and as specified by the manufacturer at maximum ambient temperature	kW					
	V					
	min					
TOB operated with a dedicated BMS and/or BSS	Yes No					

7.5 Determination of waste heat generated during endurance tests at the maximum ambient temperature

Batteries generate heat when they are in idle state or are being charged and discharged. This heat results from electrochemical reaction enthalpy changes, resistive losses, and from the energy conversion inefficiencies of secondary systems such as the BMS and BSS.

The amount of energy wasted, and released as heat, by the TOB shall be determined at the maximum ambient temperature and reported. These data shall be cogenerated during the execution of the tests in 6.x and 7.4 at the maximum ambient temperature.

The test shall be carried out with a TOB and its subsystems of the size identified in 5.3. Particular attention shall be placed on the correct scalability of the TOB waste heat value to that of a FSB.

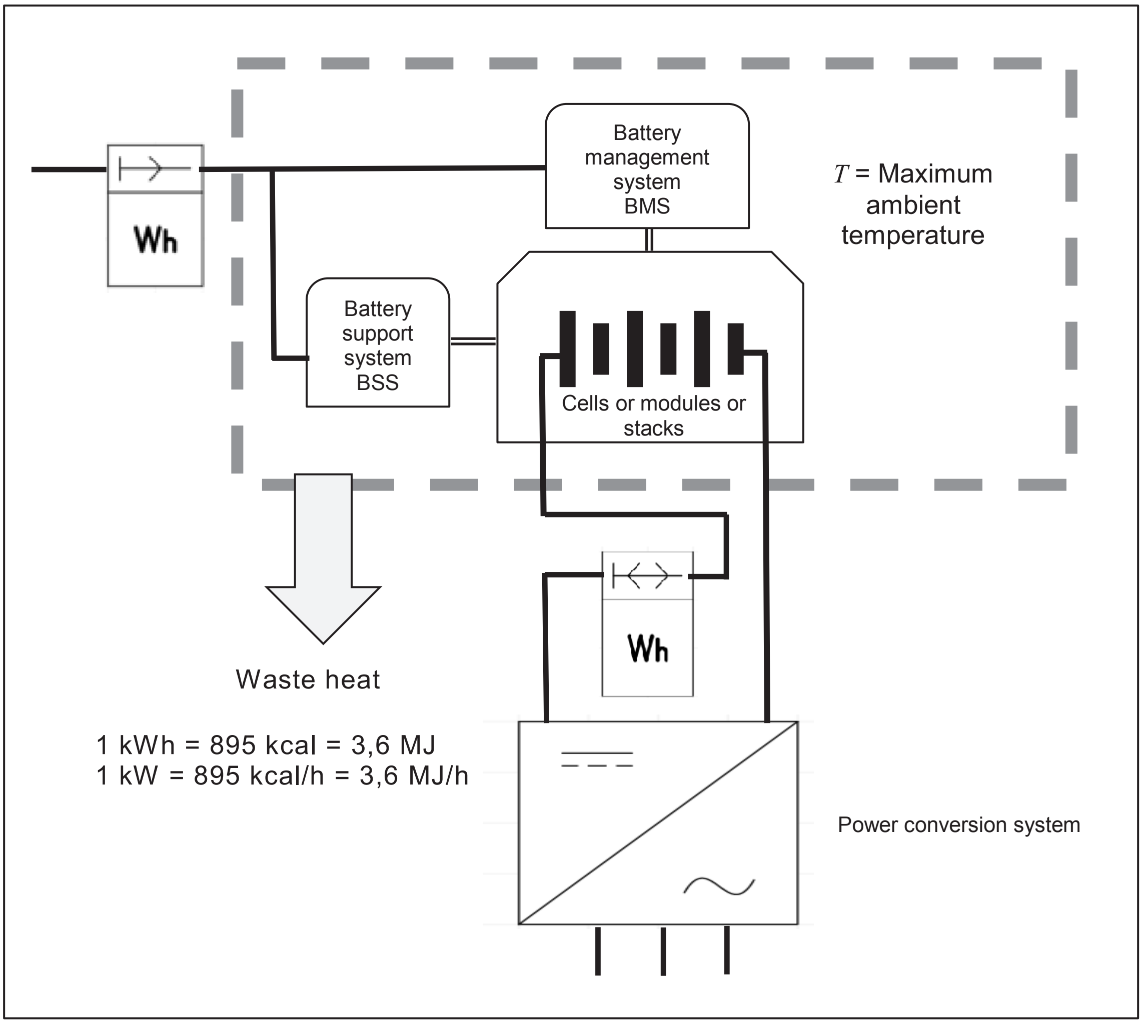


Figure 17 – Schematic view of the location of the two sets of energy values (energy to auxiliaries and energy to and from battery) to be used for the determination of the amount of waste heat generated

The amount of heat generated shall be obtained from the integration of the absolute energy values as shown in Figure 17. The integration shall be carried out over defined endurance test sequences i) and j) as specified in 7.4 and the waste energy value, E_{w} (in kWh), calculated with the formula below and reported in Table 10.

$$E_{\text{w}} = \sum E_{\text{supp}} + \sum E_{\text{charge}} - \sum E_{\text{discharge}}$$

where

E_{supp} is the energy supplied to the BMS/BSS,

E_{charge} is the energy charged into the battery,

$E_{\text{discharge}}$ is the energy discharged from the battery.

NOTE 1 1 000 Wh of energy correspond to 895 kcal or 3,6 MJ; 1 000 W of power correspond to 895 kcal/h or 3,6 MJ/h.

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

Properties	Unit	Battery of subclause				
		6.2	**6.3**	**6.4**	**6.5**	**6.5**
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Number of endurance test sequences j) over which the waste energy value, E_w, is to be determined according to 6.2, 6.3, 6.4, 6.5	No.	840	210	7	7	7
Actual number of endurance test sequences i) or j) over which the waste energy value, E_w, factor has been determined	No.					
Energy consumed (A) by the BMS and BSS of the TOB during the reported number of endurance sequences i) or j) at maximum ambient temperature	kWh					
	$°C_{max}$					
Energy charged (B) into the TOB during the reported number of endurance sequences i) or j) at maximum ambient temperature	kWh					
	$°C_{max}$					
Energy discharged (C) from the TOB during the reported number of endurance sequences i) or j) at maximum ambient temperature	kWh					
	$°C_{max}$					
Net energy released as heat by the TOB over the reported test sequences i) or j) E_w = A + B − C	kWh					
	MJ					
	kcal					
Comments and remarks concerning potential heat release scalability issues	n/a					

NOTE 2 The energy input into BMS and BSS is assumed to result in a 100 % conversion into heat.

The energy loss/heat release values are intended as guidance only and are not constant over an energy transfer cycle. The time dependency of heat generation intensity should be taken in consideration when cooling or heating infrastructure is dimensioned.

7.6 Determination of energy requirements during periods of idle state at +25 °C ambient temperature

Batteries require energy during periods of idle state to compensate for the self-discharge losses and cater for the energy needs of the BMS and BSS.

A battery in “idle state” is ready to deliver and absorb energy on demand with a reaction time as required by the application.

NOTE 1 Such reaction time may vary from few milliseconds (i.e. within the duration of a half sine wave of a.c. current) to several seconds.

The energy needed by the TOBs, when kept in idle state, shall be determined and reported.

The test shall be carried out with a TOB and its subsystems of the size identified in 5.3.

The energy required (in kWh) to keep the TOB in the idle state as defined above, shall be determined over 30 days and at +25 °C ± 3 K ambient temperature for each TOB of 6.2 through 6.5. This shall be done by physically monitoring

a) the amount of charge energy needed to keep the TOB at the SoC_{OT} level appropriate for the test sequence i) or j) of the application scenario (6.2 through 6.5),

and

b) the electrical energy consumed by the auxiliaries such as BMS and BSS so to keep the TOB at the SoC_{OT} level appropriate for duty cycle i) or j) of the application scenario (6.2 through 6.5),

and the data reported in Table 11. See also Figure 18.

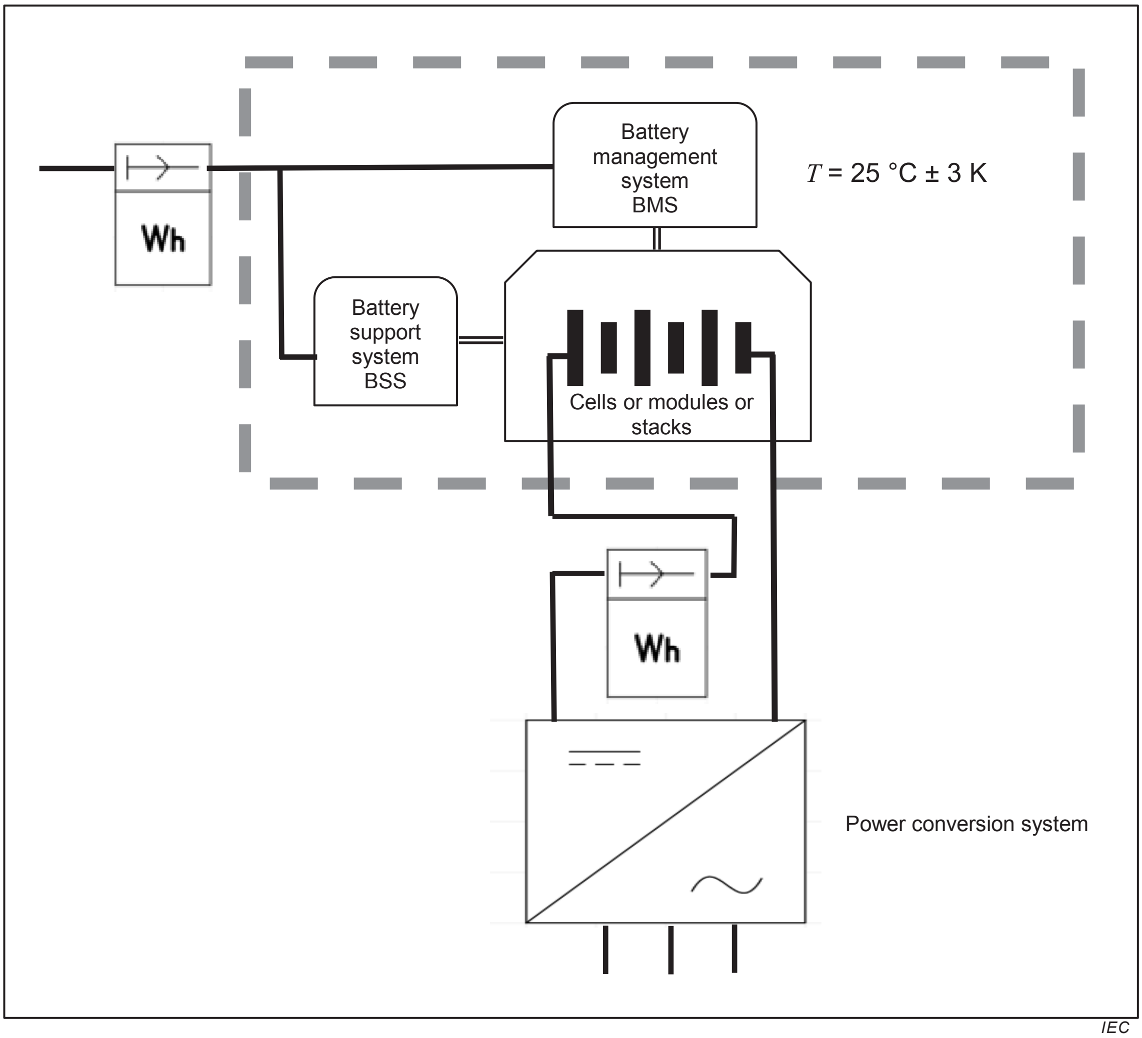


Figure 18 – Schematic view of the location of the two sets of energy values (energy to auxiliaries and energy to battery) to be used for the determination of the energy requirements during periods of idle state of the battery

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

Properties	Unit	Battery of subclause				
		6.2	**6.3**	**6.4**	**6.5**	**6.5**
Declared FSB capability	kW	500 to 1 000	180 to 360	500	3	30
Duration of time over which maintenance energy value E_M is to be determined	days	30				
Actual duration of time over which maintenance energy value E_M has been determined	days					
Energy consumed (A) by the BMS and BSS of the TOB during reported number of days in idle state at +25 °C ± 3 K ambient temperature so to maintain the mandated SoC_{OT} for endurance test purposes	kWh					
Energy charged (B) into the TOB during reported number of days in idle state at +25 °C ± 3 K ambient temperature so to maintain the mandated SoC_{OT} for endurance test purposes	kWh					
Net maintenance energy required by the TOB in idle state over the reported period. E_M = A + B	kWh					
and per day	kWh per day					

NOTE The energy requirement values obtained at +25 °C may differ at the higher or lower ambient temperatures.

Annex A
(informative)

Battery-related hazards

A.1 General

Batteries intended for electrical energy storage can be a source of dangerous voltages, elevated uncontrollable electrical currents and hazardous and toxic chemicals.

The hazards presented by such batteries have been given the necessary attention at the cell and module levels during their development and the product qualification tests. The individual battery product standards bear witness to these efforts and their consultation is highly recommended.

However, the sheer size and complexity of the planned battery systems and their associated controls make it necessary to conduct a hazard analysis very early in the planning stage to assess such hazards and risks.

Several IEC standards such as IEC 60812, IEC 61025, the IEC 61508 series, IEC 60730-1 (Annex H) and other relevant functional safety standards and methods (FTA, FMEA) can be used for such assessments.

This assessment should be carried out, prior to product procurement, in close collaboration with the battery manufacturer, the battery system builder and integrator and the future EES system operator.

A.2 Examples

A non-exhaustive list of hazard sources and events is listed in Tables A.1 and A. 2. Their occurrence is tied to the chemistry, the design of the cells and of the full-sized battery and battery plant.

Table A.1 – Non-exhaustive listing of potential battery-related hazards to be taken in consideration in risk assessment activities

Examples of hazards caused by the battery itself
Emission of combustible, toxic or explosive gases
Emission of combustible, toxic or corrosive liquids
Ejection of combustible or toxic solids
Ground short currents
Fire or explosions
Heat damage and associated personal injuries
Loss of system functionality
Electrical arcs and shocks

Table A.2 – Non-exhaustive listing of potential installation-related hazards to be taken in consideration in risk assessment activities

Examples of external hazards impacting on the battery
Loss of air-conditioning and battery cooling
Loss of battery room ventilation
Loss of battery heating controls
Loss of battery voltage control functions
Over-discharge of cells due to a ground fault
Overcharge due to control function loss, data drift or software error
Overcurrent due to control function loss, shunt calibration error or drift
Short-circuit in control and diagnostic cabling on the battery
Massive shorts in the power cabling from the battery to the PCS or to the d.c. load
Loss of BMS/BSS functions
Seismic events
Fire in immediate vicinity of the battery
Sprinkler action, drip-water exposure and flooding
Crushing of cells due to rack or building collapse
Vandalism and theft
Operator errors
Improper disposal and recycling of cells and modules

Bibliography

The following International Standards and Technical Reports give valuable background information on the cells and batteries involved in the tests according to this part of IEC 61427. The status of the most recent version can be found at www.iec.ch.

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available from: http://www.electropedia.org)

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

IEC 60730-1, *Automatic electrical controls – Part 1: General requirements*

IEC 60812, Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)

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

IEC 60896-21, *Stationary lead-acid batteries – Part 21: Valve regulated types – Methods of test*

IEC 60896-22, *Stationary lead-acid batteries – Part 22: Valve regulated types – Requirements*

IEC 61025, Fault tree analysis (FTA)

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

IEC 61508 (all parts), Functional safety of electrical/electronic/programmable electronic safety-related systems

IEC 61508-7, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 7: Overview of techniques and measures*

IEC TR 62060, *Secondary cells and batteries – Monitoring of lead acid stationary batteries – User guide*

IEC 62133, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications*

IEC 62259, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Nickel-cadmium prismatic secondary single cells with partial gas recombination*

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

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

IEC 62485-3, *Safety requirements for secondary batteries and battery installations – Part 3: Traction batteries*

IEC 62619, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for large format secondary lithium cells and batteries for use in industrial applications*[1]

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

IEC 62675, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Sealed nickel-metal hydride prismatic rechargeable single cells*

IEC 62897, *Stationary Energy Storage Systems with Lithium Batteries – Safety Requirements* [2]

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1 Under consideration.

2 Under consideration.

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