IEC TS 62933-3-1

Edition 1.0 2018-08

TECHNICAL SPECIFICATION

colour inside

Electrical energy storage (EES) systems –
Part 3-1: Planning and performance assessment of electrical energy storage systems – General specification

IEC TS 62933-3-1:2018-08(en)

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CONTENTS

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ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –

Part 3-1: Planning and performance assessment of electrical energy storage systems – General specification

FOREWORD

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- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical Specification IEC 62933-3-1 has been prepared by IEC technical committee TC 120: Electrical Energy Storage (EES) Systems.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
120/118/DTS	120/123/RVDTS

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

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

A list of all parts in the IEC 62933 series, published under the general title *Electrical energy storage (EES) systems*, can be found on the IEC website.

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

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

IEC 62933-2-1 should be used as a reference when selecting testing items and their corresponding evaluation methods as well as principal parameters. Principal terms used in this document are defined in IEC 62933-1. Environmental issues are covered by IEC TS 62933-4-1. The personnel safety issues are covered by IEC TS 62933-5-1.

ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –

Part 3-1: Planning and performance assessment of electrical energy storage systems – General specification

1 Scope

This part of IEC 62933 is applicable to EES systems designed for grid-connected indoor or outdoor installation and operation. This document considers

- necessary functions and capabilities of EES systems
- test items and performance assessment methods for EES systems
- requirements for monitoring and acquisition of EES system operating parameters
- exchange of system information and control capabilities required

Stakeholders of this document comprise personnel involved with EES systems, which includes

– planners of electric power systems and EES systems
– owners of EES system
– operators of electric power systems and EES systems
– constructors
– suppliers of EES system and its equipment
– aggregators

Use-case-specific technical documentation, including planning and installation specific tasks such as system design, monitoring and measurement, operation and maintenance, are very important and can be found throughout this document.

NOTE This document has been written for AC grids, however parts can also apply to DC grids.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60721-1, *Classification of environmental conditions – Part 1: Environmental parameters and their severities*

IEC 62351 (all parts), *Power systems management and associated information exchange – Data and communications security*

IEC 62443 (all parts), *Industrial communication networks – Network and system security*

IEC 62933-1:2018, *Electrical energy storage (EES) systems – Part 1: Vocabulary*

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

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

ISO/IEC 27000, *Information technology – Security techniques – Information security management systems – Overview and vocabulary*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62933-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
idle, adj.
<period of time> time period where the EES system does not or is not able to perform any grid tasks related to active output power at the point of connection (POC)

3.1.2
recovery time
duration needed by an EES system to recover from a duty cycle so that the following duty cycle is within its specified conditions for a certain operating mode and at continuous operating conditions

Note 1 to entry: The definition is loosely based on IEC 60050-447:2010, 447-05-08.

3.2 Symbols

P active power

Q reactive power

S apparent power

U voltage

I current

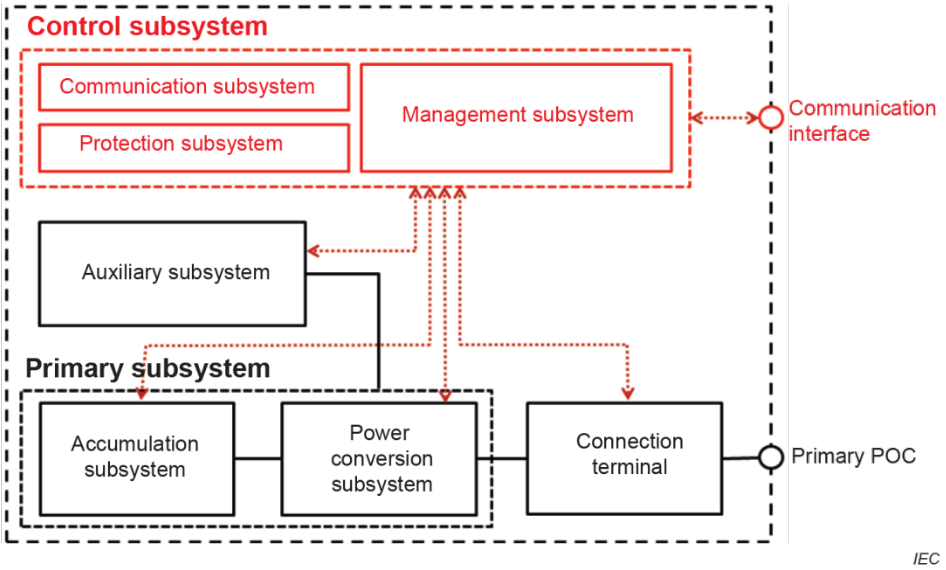
$\cos\varphi$ power factor

f frequency

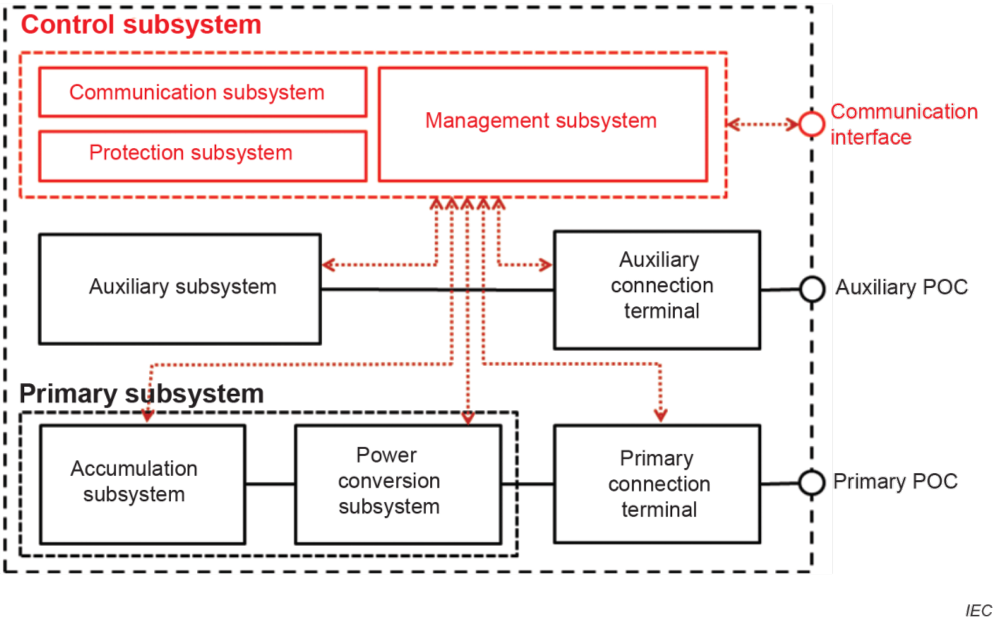
4 General structure of EES systems

4.1 Architecture of an EES system

The typical architecture of an EES system, which internally feeds the auxiliary subsystem, is given in Figure 1 a).



a) EES system without auxiliary POC



b) EES system with auxiliary POC

Figure 1 – Typical architectures of EES systems

If the auxiliary subsystem is fed from another feeder, the optional architecture of an ESS system is shown in Figure 1 b).

In 4.2 the subsystems of an EES system are described. In general, for all subsystems, the contribution to the overall system efficiency, for example roundtrip efficiency, shall be indicated.

4.2 Subsystem specifications

4.2.1 Accumulation subsystem

The energy capacity of the accumulation subsystem of the EES system has to be evaluated in an appropriate way with respect to the energy form. The energy capacity of the accumulation subsystem directly influences the rated input and output energy capacity at the primary POC, i.e. it influences the active input and output power values at the primary POC as well as the duration the active input and output power can be applied at the primary POC.

A widely-used approach for classifying EES systems is the determination according to the form of energy used in the accumulation subsystem. A classification example of EES systems according to energy form in the accumulation subsystem is shown in Figure 2.

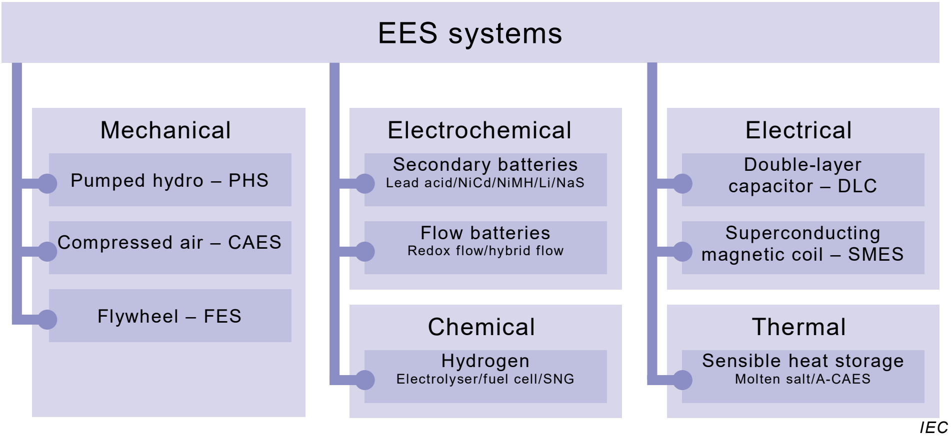


Figure 2 – Example of classification of EES systems according to energy form

4.2.2 Power conversion subsystem

The power conversion subsystem converts the power of the accumulation subsystem into electrical power at the POC, typically AC output power during discharge of the accumulation subsystem, and can convert grid AC input power to suitable power for charging the accumulation subsystem. This conversion can be performed by electrical and/or mechanical systems. The power conversion subsystem influences the apparent power characteristic of the EES system. The power conversion subsystem can also influence the power quality at the POC.

Generally the power conversion subsystem is connected to the accumulation subsystem and to the (primary) connection terminal. For planning issues the power conversion subsystem shall also include all power transfer apparatus between the connection terminal and the accumulation subsystem, for example any kind of power transformer, sine filter or switching elements.

4.2.3 Auxiliary subsystem

All necessary equipment intended to perform EES system auxiliary functions shall be used, for example heating, ventilation, fire suppression system and air conditioning system.

4.2.4 Control subsystem

A system for monitoring and controlling the EES system shall be used. A control subsystem may include a communication subsystem, protection subsystem and management subsystem. During the planning phase the required remote control capabilities and the operation modes that the control system will support shall be stated, considering the applicable local grid code requirements.

The EES system shall be designed in such a way that a supply outage does not affect the EES system security and the ability of the EES system to start up again. The maximum outage duration should be considered (for example a specific back-up power has to be designed). A safe disconnection and safe system shutdown concept shall be agreed between the supplier and user of the EES system.

All protection functions shall be described with functionality and trigger values.

5 Planning of EES systems

5.1 General

The planning of an EES system is dependent on the topology of the grid as well as on the power demand and generation available at the POC. There is a wide variety of grids that have EES systems connected. These variations impact EES system specifications including:

- functionality (peak shaving, frequency support, virtual synchronous machine behaviour, etc.),
- accumulation subsystem (energy capacity, power, etc.),
- power conversion subsystem (response time, droop control, power, short-circuit power, etc.).

The EES system requirements should be clearly outlined in order to provide the best solution and to maximize system adaptability and performance benefits. The needs of the electrical network may also need to be considered. During the planning phase, at the system level and after the application has been defined, the EES system requirements have to be specified according to the application.

The results of the sizing of EES systems (examples are given in Annex A) are the relevant parameters of the EES system including

– rated input and output power
– short duration input and output power
– rated energy capacity
– response time parameters
– auxiliary power consumption
– self-discharge
– roundtrip efficiency
– duty cycle roundtrip efficiency
– recovery times
– end-of-service life values

Clause 5 helps the planner define the specifications in such a way that EES system suppliers have all the relevant information to design a system.

Clause 5 provides information needed to assess the performances of a system. This ensures that potential users (such as a utility) can have the necessary information about the EES system from the system supplier. In particular maintenance requirements and end-of-service life values shall be provided and be compatible with the application.

In general the rated value of a quantity is used for specification purposes, established for a specified set of operating conditions of a component, device, equipment, or system. When specifying the rated values for planning purposes of an EES system, the critical operating limits of the power capability chart, capability reductions due to ageing, altered environmental conditions and other limiting factors shall be taken into account. All rated values used for planning purposes shall be values related to the end-of-service life.

Other parameters such as availability shall be provided and taken into account during the planning phase.

Auxiliary power consumption varies throughout the service life of the EES system and shall therefore be assessed for the whole service life of the unit and for the environmental conditions expected at the installation site. The influence on the overall EES system efficiency of the extreme weather conditions should also be considered (see 5.2.3).

NOTE End-of-service life value definitions are given in IEC 62933-1. The test of auxiliary power consumption is included in IEC 62933-2-1.

5.2 EES system environment

5.2.1 General

Subclause 5.2 describes the environment of the EES system, which shall be considered for planning an EES system. Subclause 5.2 contains three further subclauses:

- grid parameters and requirements, which include mainly electrical parameters, constraints, operational ranges and requirements of the electrical power grid at the (primary) POC (5.2.2),
- service conditions, which include the non-electrical environment of the EES system (5.2.3),
- standards and local regulations, which include additional requirements according to applicable standards and regulations (5.2.4).

According to the place of installation the site-specific requirements shall be considered during the planning phase. Examples of site-specific requirements of an EES system are given in Annex B.

In addition, the classification of environmental conditions in IEC 60721-1 shall be considered in the planning phase.

5.2.2 Grid parameters and requirements

5.2.2.1 Grid parameters

The main parameters of the grid at the POC, to which the EES system is going to be connected, shall be considered in the planning phase. These parameters include

- nominal voltage of the service
- highest voltage for components
- temporary voltage variations
- nominal frequency
- continuous normal frequency variation
- temporary frequency variations
- short-circuit current and duration
- neutral connection

These parameters are typically provided by the grid operator and may be included in specific grid requirements based on local grid codes.

5.2.2.2 Protective earthing

For earthing, refer for example to IEC 60364 (all parts) and local regulations.

5.2.2.3 Emissions and disturbances of the EES system at the POC

The contribution to harmonic voltage and current disturbances or other undesired effects at the POC of the EES system shall be declared clearly by the system supplier to assess possible issues with grid codes already at the planning stage (see also IEC 62933-2-1 for appropriate testing).

5.2.2.4 Immunity of the EES system

The EES system shall be immune against possible, harmful impacts from the electrical environment. For example, in EMC-sensitive cases, such as the installation of an EES system in a substation, the EES system should implement an immunity level according to the requirements stated in IEC 61000-6-5.

5.2.3 Service conditions

5.2.3.1 General

Subclause 5.2.3 includes all non-electrical environmental conditions such as altitude, humidity, etc.

Where applicable, EES system planners should refer to IEC 60721-3-3, IEC 60364-5-51 or IEC TS 62933-4-1 for guidelines on environmental conditions.

5.2.3.2 Earthquake resistivity and endurance

Where appropriate the EES system and its support structure shall withstand earthquakes. In general the EES system and its support structure should be designed in accordance with the seismic classification area of the site and local codes. The EES system should achieve at least the same performance against earthquakes than the rest of the grid equipment.

For soil acceleration levels, as well as test methods, refer to IEC 60068-3-3 and local regulations. Additionally local conditions, for example environmental conditions, shall be taken into account.

Where an earthquake-proof standard is specified, the EES system should comply with this standard. However, where a large influence by vibration is expected, additional standards and measures should be considered.

5.2.3.3 Ambient temperature and solar radiation

The EES system shall be designed and constructed to withstand the stress generated due to temperature variation considering the effects of the ambient temperature and the solar radiation on the operating temperature. Unless specifically ordered otherwise by the customer, the cooling/heating system shall be sized appropriately while considering the most demanding operational and weather conditions of the site.

5.2.3.4 Protection against dust and corrosive atmospheres

Where required, the EES system shall be equipped with protection against dust and corrosive atmospheres according to the operating environment. The structure of the EES system shall be easily maintained.

5.2.3.5 Inundation

If required, the measures against flood according to local regulations shall be applied. These regulations can depend on installation conditions such as location, characteristics of the region and principle and scale of the EES system. Where flood protection measures are specified by local regulation, the EES system should comply with that regulation. However, where flooding probability is not negligible, protective measures should be applied irrespective of the absence of a local regulation.

5.2.3.6 Wind

If required, the wind protection measures should conform to related regulations depending on installation conditions such as location, characteristics of the region, principle and scale of the EES system. In case wind protection measures are specified by local regulation, the EES system should comply with that regulation. However, where large influence by wind is expected, protective measures should be applied irrespective of the absence of a local regulation.

5.2.4 Standards and local regulations

5.2.4.1 General impact on EES system design

All standards and local regulations which impact EES system design shall be explored in the planning phase.

5.2.4.2 Emissions of EES system

To minimize the influence on the environment caused by the installation of an EES system, two categories should be considered. Specifically, one category is a regular occurrence, such as noise exhaust gas and EMC; the other category is an irregular occurrence, such as fire, explosion collapse and disposal. For environmental impacts refer to IEC TS 62933-4-1; for safety refer to IEC 62933-5 (all parts) and for EMC emissions refer to IEC 61000-6-4.

5.3 Sizing of EES systems

5.3.1 Requirements at primary POC

Sizing of EES systems is usually connected to the identification of one or more suitable duty cycles, which the EES system may typically have to perform at the primary POC to meet its operational requirements. Additionally it is necessary to know the (minimum and maximum) recovery times which are available to restore the EES system between duty cycles. In addition, the required service life time of the EES system should be specified with regard to the proper consideration of system ageing and possibly necessary maintenance and refurbishment works.

The specification of identified duty cycles should include

- duration of the duty cycle and the expected frequency (number of times per day/week/year);
- required pattern of the active power at the primary POC of the EES system, possibly including allowed tolerance ranges (maximum overshoot and/or undercut);
- required pattern of the reactive power at the primary POC of the EES system, possibly including allowed tolerance ranges (maximum overshoot and/or undercut).

The specified pattern of active and reactive power at the primary POC can include durations in which active and/or reactive power is zero. From these patterns it should be possible to derive ramp rates of active and reactive power.

Since the initial value at the beginning of each duty cycle should be within a certain energy content range, a recovery cycle may be necessary to bring back the EES system to a state where it is possible to perform duty cycles again. The degrees of freedom in recovery cycles depend mainly on grid requirements. With regard to sizing the EES system, the following characteristic values of the recovery process should be given:

a) minimum duration
b) maximum duration
c) range of allowed active output or input power, including maximum and minimum active output or input power values
d) possible requirements or constraints regarding reactive input and output power
e) maximum allowed ramp rates of active and reactive power
f) allowed range of power factor values at primary POC
g) possible requirements regarding power factor

Regarding the operational features of the EES system, which should be represented by the identified duty cycles and recovery times, not all possible (worst) case situations of the electrical power grid regarding power and energy demand at the primary POC can be covered. But the required duty cycles and the specified recovery times should cover most probable grid situations. Future developments regarding power generation and power consumption in the electrical power grid as well as changes to the grid structure should also be considered when specifying duty cycles and recovery times.

For different operational requirements, sets of duty cycles with different time durations (short-term and long-term durations) and different maximum power values might be identified. In this case superposition of duty cycles for different operational features might be necessary to properly describe the overall operational capability of an EES system.

The following characteristics of the required duty cycles should be identified:

– response time
– overall duration
– initial energy content
– energy content value at the end of the duty cycle
– maximum value of active output power
– maximum value of active input power
– speed of change of active power values
– speed of change between active input or output power
– maximum partial energy output, i.e. maximum energy output in a time period within the duty cycle with only active power output at the (primary) POC. This maximum energy output value at the (primary) POC is the mathematical integral of active output power over the duration of the time period with only active power output
– maximum partial energy input, i.e. maximum energy input over a time period within the duty cycle with only active power input at the (primary) POC. This maximum energy input value at the (primary) POC is the mathematical integral of active input power over the duration of this time period with only active power input
– maximum value of reactive output power
– maximum value of reactive input power
– speed of change of reactive power values
– speed of change between reactive input and output power

Examples of required duty cycles for some EES system applications are given in Annex A.

5.3.2 Sizing recommendations

The required duty cycles, the specified recovery times and the required service life can be used to derive the size of the EES system.

With the sized EES system it should be possible for the EES system supplier to show the system user that with a certain operation strategy of the EES system the required duty cycles can be met and the system can recover in specified time periods over the whole service life.

To ensure the required EES system capability over the whole service life, it is necessary that the EES system parameters' rated active output power, duration at rated active output power, rated active input power and duration at rated active input power are chosen appropriately. Power ramp rates, which can be derived from required duty cycles, should be met by response time parameters of the sized EES system over the whole service life.

Regarding the proper sizing of the EES system over the whole service life, maintenance and service works, for example periodically necessary calibration cycles, should also be taken into account.

All (superposed) duty cycles which are necessary to describe the overall operational capability of the EES system should be taken into account to identify the characteristic values of duty cycles. The recovery cycles and their characteristic values may also be superposed.

5.4 Main electrical parameters of EES systems

5.4.1 General

For EES systems 5.4.2 to 5.4.7 include the main electrical parameters related to system performance at the (primary) POC, possibly including effects at the auxiliary POC. The main parameters representing the electrical performance of the EES system may include, but should not be limited to, the values given in 5.1.

In the planning phase, the EES system should be designed and reviewed based on the requirements at the POC and on the customer requirements. During this process, the planner should focus on the performance parameters from the specification and related data, ensuring the coordination of each subsystem and/or equipment provided by each respective supplier (see Table 1). During the planning phase, the performance degradation of the EES system should also be considered.

Constrains between power rating, available energy, ambient conditions and other internal/external factors shall be considered.

Grid-connected EES systems shall meet performance specifications throughout their service life. This includes their service life under use conditions such as operation patterns (see IEC 62933-1:2018, Figure 1), environmental conditions, maintenance cycle, etc.

Table 1 – Points of attention for planning phase

Energy capacity values	Input and output power values (active and reactive)	Round trip efficiency	End-of-service life values	Response time parameters
Rated energy capacity values to achieve service life Necessary energy capacity values for the specified application	Rated input and output power Rated power for on-grid and off-grid use Short-term power ratings	Round trip energy efficiency Duty cycle round trip energy efficiency for the specified application Power consumption in auxiliary and control subsystem and internal losses Loss of energy due to self-consumption / self-discharge	Satisfactory design and maintenance plan to keep specified values of performance parameters	Required response time (for autonomous operation, load-following operation, scheduled operation and remote dispatch) Required response time from standby state to start up Response time from active input power state to active output power state

5.4.2 Input and output power rating

The rated active input and output power should be chosen according to the intended usage of the EES system. Both rated power values shall be valid till end-of-service life.

Rated active input and output power values shall be defined at the (primary) POC and shall be equal to the ‘rated active power during charge’ and the ‘rated active power during discharge’ defined in IEC 62933-1. The short duration input and output power values shall be equal to the ‘short duration power during charge’ and ‘short duration power during discharge’ defined in IEC 62933-1.

The selection and specification of both the power conversion subsystem and accumulation subsystem of the EES system shall be considered during the planning phase.

NOTE The rated input and output power can be different in EES systems.

5.4.3 Rated energy capacity

In order to provide the required rated energy capacity and the required active input and output power values at the primary POC for the specified durations, the accumulation subsystem of the EES system should be designed appropriately during the planning phase.

For EES system planning the rated energy capacity shall be the capacity value at the end-of-service life considering the worst case operation limits (e.g. degradation due to highest or lowest operation temperature).

The ‘duration at rated active output power’ value shall be the minimum time duration with which the EES system is able to deliver the rated active output power continuously, starting from full state of charge, providing continuously the rated active output power, measured at the primary POC, and finally reaching the end-of-discharge condition. The duration at the rated active output power is intended at the end of the service life.

The ‘rated output energy capacity’ shall be derived by multiplying the rated active output power with the duration at the rated active output power. So the ‘rated output energy capacity’ is equal to the ‘rated energy capacity’ defined in IEC 62933-1. Therefore it is assured that at the end-of-service life the EES system can provide the rated output power value at the primary POC for a certain duration.

The ‘duration at rated active input power’ value shall be the minimum time duration with which the EES system is able to consume continuously the rated active input power, starting from an empty state of charge, providing the rated active input power continuously, measured at the primary POC, and finally reaching the end-of-charge condition. The duration at the rated active input power is intended at the end of the service life.

The ‘rated input energy capacity’ shall be derived by multiplying the rated active input power with the duration at the rated active input power.

Response time parameters shall be designed from the time when the EES system receives the command signal or detects changes in the nominated grid parameter, to the time when the system reaches a specified response.

5.4.4 Auxiliary power consumption

Auxiliary power consumption shall be considered during the planning phase.

NOTE Explanations about auxiliary power consumption are included in IEC 62933-2-1:2017, Clause 5.

5.4.5 Self-discharge

Refer to IEC 62933-1 and IEC 62933-2-1.

5.4.6 Roundtrip efficiency

The energy consumption of an auxiliary subsystem shall be taken into consideration for the calculation of the roundtrip efficiency.

NOTE 1 Explanations about roundtrip efficiency are included in IEC 62933-2-1:2017, Clause 5, and the definition of roundtrip efficiency is included in IEC 62933-1.

NOTE 2 The terms duty cycle and duty cycle efficiency are defined in IEC 62933-1. The EES system supplier will state in the planning phase the idle times needed when operating the system to perform the user´s duty cycle.

5.4.7 Duty cycle roundtrip efficiency

For duty cycle and duty cycle roundtrip efficiency refer to IEC 62933-1 and IEC 62933-2-1.

5.4.8 Recovery times

The duration necessary to recover the EES system for the next duty cycle shall be considered during the planning phase.

5.4.9 End-of-service life values

In the planning phase the expected life time needed shall be specified. At the end-of-service life, EES systems no longer comply with the end-of-service life values (see IEC 62933-1). Examples are:

- The actual energy capacity or the actual input energy capacity of the EES system is less than the end-of-service life value.
- The power during system charging or discharging is less than the end-of-service life value.
- The round trip energy efficiency is less than the end-of-service life values.
- The response time parameters deteriorate for the end-of-service life values.

From the viewpoint of service life, performance parameters are typically categorized into two types of degradation characteristics as shown in Figure 3:

a) The performance is deteriorated over time: for example actual energy capacity and round trip energy efficiency.

b) The performance is not significantly deteriorated over time: for example input and output power rating.

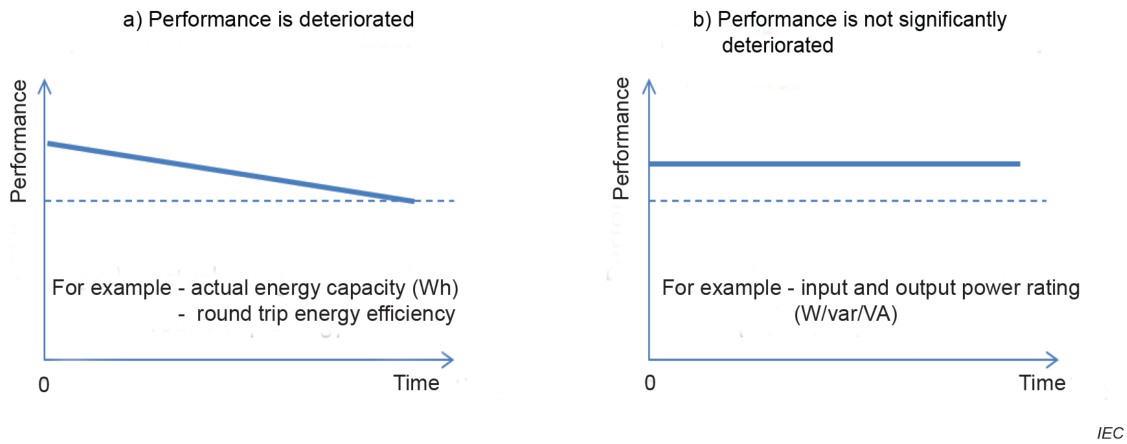


Figure 3 – Sample performance versus time characteristics for EES systems

The performance degradation in EES systems is generally caused by ageing or charge-and-discharge cycles, as well as by some failures. If performance degradation has occurred in the EES system but is recovered by maintenance or repair work, the EES system is still considered in service life.

NOTE If the system parts replacement or the maintenance services periods are not performed as expected, the service life is no longer assured.

Typical items to consider for the design of service life of the EES system are shown in Figure 4. Both degradation characteristics and maintenance plan should be taken into consideration to set the service life, which should be subjected to agreement between the user and system supplier.

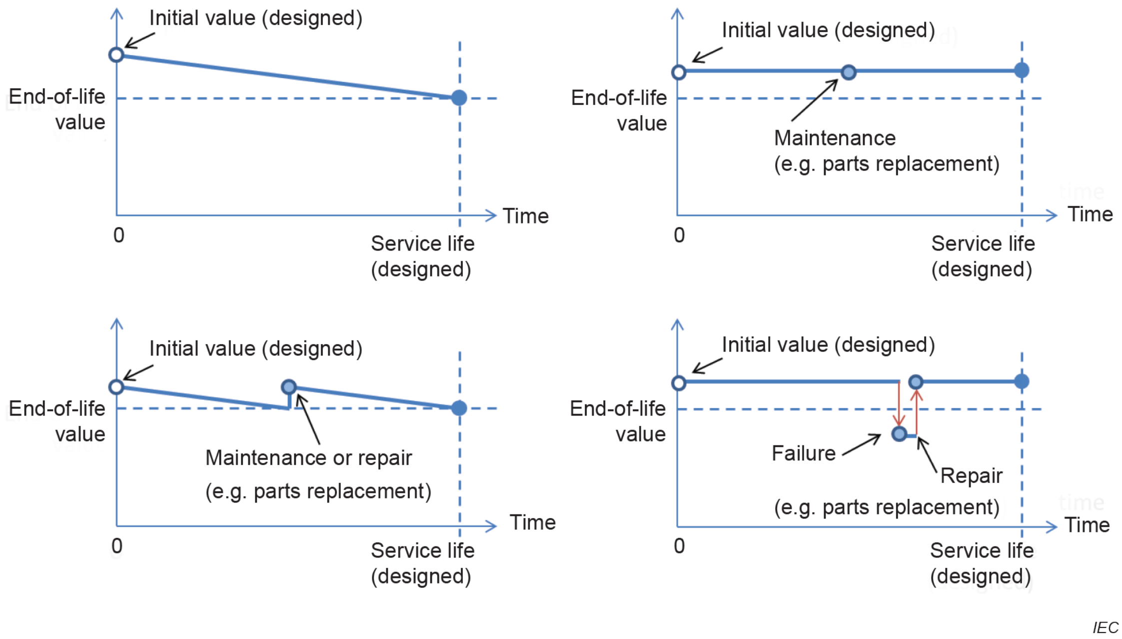


Figure 4 – Sample consideration to design the service life of EES systems

5.5 Functional system performance

5.5.1 General

5.5.1.1 Overview

Subclause 5.5 provides different options to configure the control system of an EES system. Not all EES systems might have the described functionality, for example EES systems providing no grid services.

5.5.1.2 Typical applications

The application and usage of an EES system varies depending on its intended purpose and location. EES systems can be classified into three classes (see IEC 62933-2-1:2017, 4.2). Five examples of representative applications are provided as follows.

Class A: Short duration applications require the EES system to supply the required power over a duty cycle for a short period of time. Possible applications include:

1) Frequency regulation

   The EES system has the capability to support grid frequency within a specified tolerance.

   NOTE The definition of frequency regulation is included in IEC 62933-2-1.

2) Reduction of power fluctuations

   The EES system has the capability to reduce fluctuating power, for example caused by some renewable energy systems or highly dynamic loads.

3) Voltage regulation

   The EES system has the capability to stabilize the voltage of the grid.

Class B: Long duration applications require the EES system to supply a duty cycle for a long period of time. A possible application is:

4) Peak shaving/peak shifting

The EES system has the capability to use the stored energy for peak demand or to store excess energy that has been generated. This application is very useful in transmission and distribution systems, in order to optimize the existing assets.

Class C: The EES system can be used for back-up power purposes in emergency cases without relying on an external power source. A possible application is:

5) Back-up power

The EES system can have the capability to supply AC power to electric power grids to operate critically important systems in accordance with the system specifications as defined between the user and system supplier. The EES system can therefore reduce the risks of major blackouts.

A combination of applications with different operation times may be required to cover the required functionality at the POC.

A grid-connected EES system could impact the power quality of the power grid at the POC, grid protection and grid security. Therefore, the items that follow regarding security and safety aspects should be taken into consideration.

In general, supply reliability (power failure), power quality (voltage, frequency, power factor, etc.) and fault current should be considered.

5.5.1.3 Security of supply

The ability of EES systems to support peak demands and renewable generation surplus will increase the security of supply to specific parts of the grid after the EES system installation.

5.5.1.4 Grid stability

The following parameters shall be provided by the EES system supplier to the relevant electric power system operator according to requirements of the network operator:

- response time
- ramp rate capability
- short-circuit current contribution
- voltage ride through capability (low- / over-voltage ride through (LVRT/OVRT))
- $P(f)$ regulation characteristic
- $Q(U)$ capability

For all features the actual response characteristic shall be clearly provided. Regarding grid stability requirements the EES system shall comply with grid codes and local connection rules. The supplier and user of the EES system should analyze and agree on the impact of the EES system to the grid.

The accumulation subsystem provides the main functionality of an EES system which typically is the capability to store energy and to exchange active input and output power at the primary POC. If the accumulation subsystem does not allow charging or discharging, EES systems may still be able to provide grid services which do not have significant active input or output power at the primary POC.

5.5.1.5 Quality of supply

The normal operation of a grid-connected EES system should not negatively affect the power quality of the grid (e.g. voltage harmonics and flicker).

5.5.2 Operation states of control subsystem

There are different kinds of operation states which can be adopted for the control of an EES system and which are presented in Figure 5 as an example. All these operation states are not necessarily implemented on the control system of an EES system and it is the responsibility of stakeholders to specify the operation modes required for a particular application.

Figure 5 shows one example for possible operation states of an EES system.

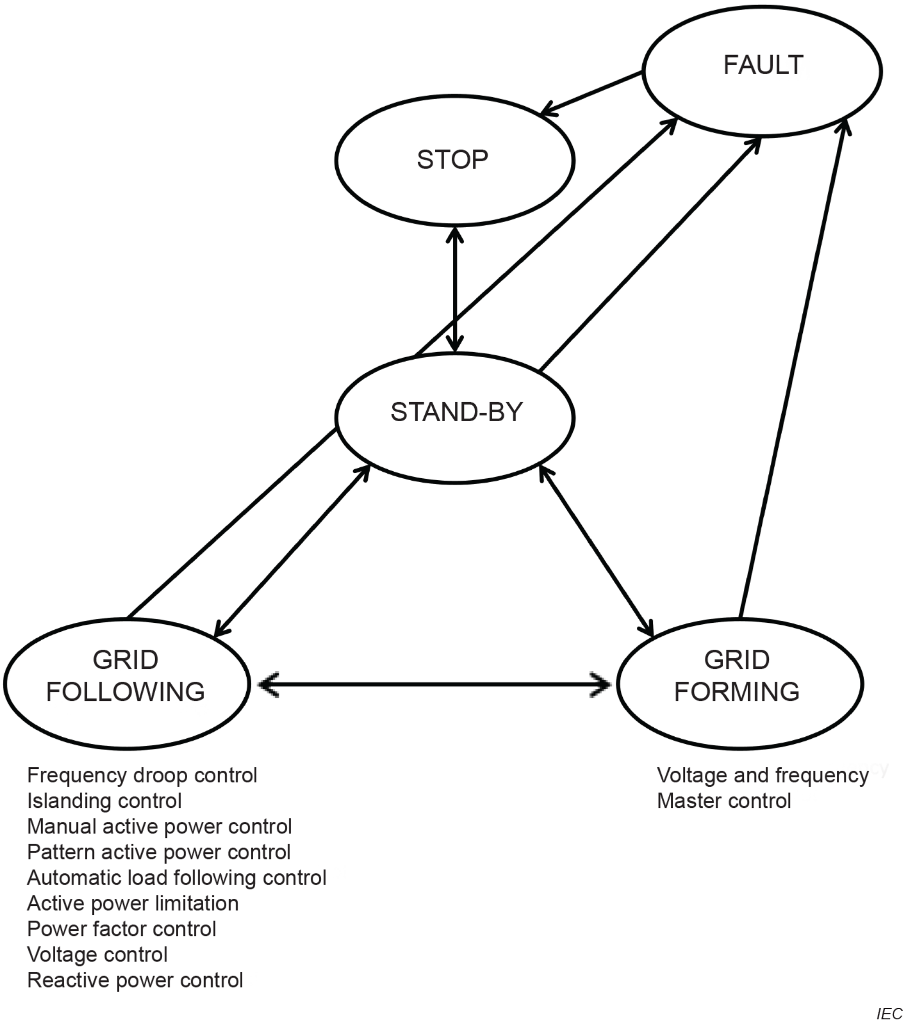


Figure 5 –Example of EES system operation states

When grid connected, the EES system can then be operated with different kinds of activated controls.

5.5.3 Grid frequency support

In this mode the system will support the grid frequency, with part or the whole of its active power capabilities. With the activation of the grid frequency regulation control mode, the EES system shall be capable of activating active power response as a result of a frequency deviation, in an automatic mode, to support the grid stability.

The specified strategy for frequency support will be part of the system controller program, implementing the related local grid code requirements. The user will typically set in the system controller the following parameters:

1) the percentage of rated active power that is reserved for frequency support,

2) the frequency support strategy that the system shall perform.

The rest of the operation modes could be running simultaneously as long as the system limits are respected with regard to power and energy ratings.

With the activation of the grid frequency regulation control mode, the EES system shall be capable of activating the active power response to the frequency deviation with a programmable droop and for a frequency greater (or lower) than a programmable frequency threshold.

Figure 6 provides an example of automatic grid support strategy against frequency variations at the POC.

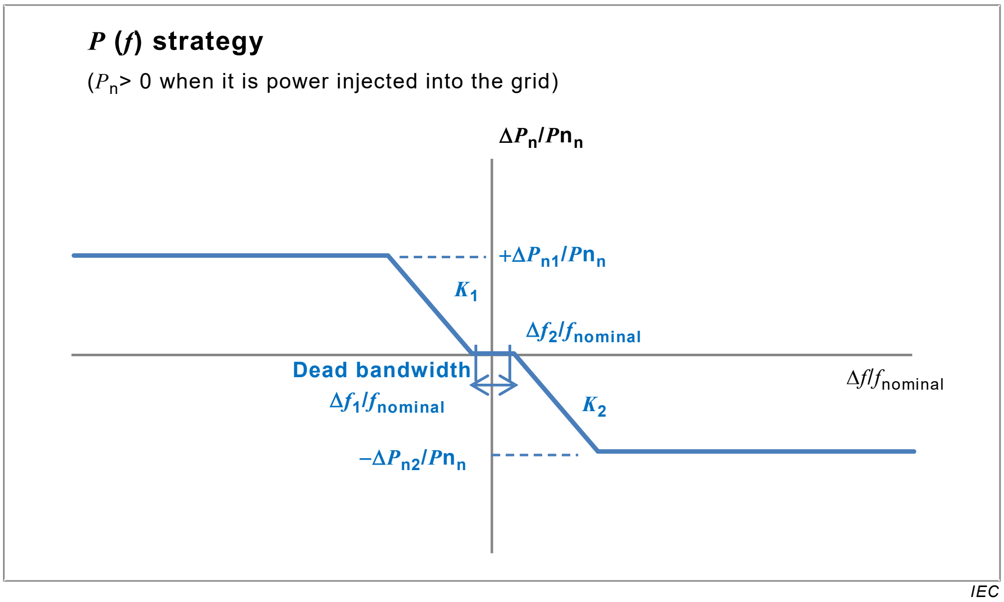


Figure 6 – Example for $P(f)$ strategy

NOTE The dead band width can be adjusted down to 0 mHz.

In order to avoid disconnection due to over-frequency protection while discharging or under-frequency protection while charging, the EES system shall implement a control mode to reduce/increase active power output as a function of frequency variation. The activation of such control mode shall not cause steps or oscillations in the output power.

5.5.4 Islanding control and black start capability

Islanding control refers to the grid forming control modes; with the activation of such a control mode, the EES system shall be capable of supporting the voltage and the frequency of a local network with loads and other generators. Islanding control mode can either refer to the procedure to recover from the shutdown of the network (black start) or to the intentional disconnection of a local network from the main power system. For black start performance parameters refer to IEC 62933-2-1.

5.5.5 Active power limitation

With the activation of the active power limitation mode, the EES system is capable of reducing its active power to a set point provided by the system operator. The set point shall be adjustable in the complete operating range of the EES system. The EES system shall be capable of carrying out the limitation as fast as technically feasible.

5.5.6 Manual active power control

The system controller will set the electric power's active input-output power value at the primary POC and operate it at that value. With the specified value, the operation will continue until a stop signal is received or when the operation ends. An example for possible active output power setting manually is shown in Figure 7.

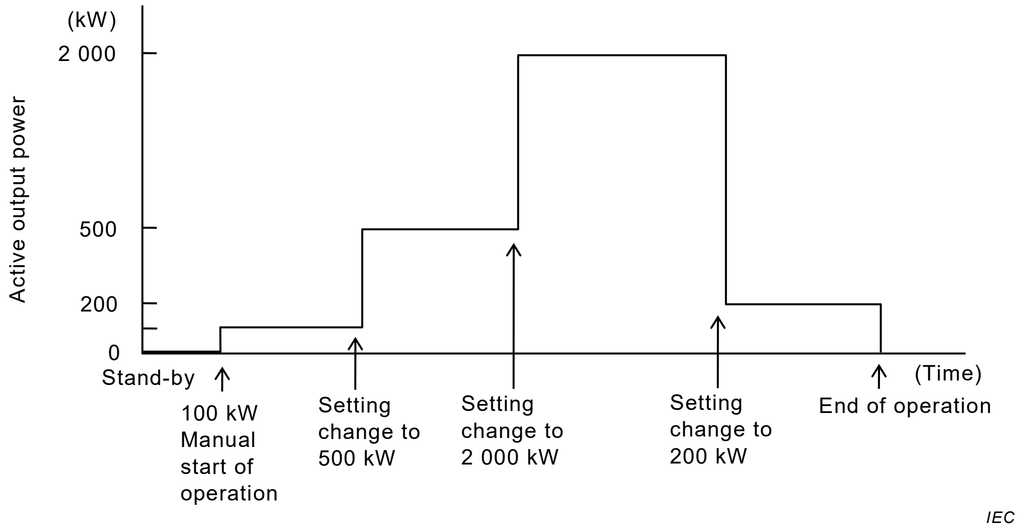


Figure 7 – Example of setting of active output power at primary POC

5.5.7 Pattern active power control

The system automatically operates according to the operation pattern set up beforehand in this operation mode. The example in case the active input and output power and start time values are set up beforehand is shown in Table 2 and Figure 8.

Table 2 – Example of day pattern operation

No.	Stating time	Power		No.	Starting time	Power	
1	9:00	Stand-by	0 kW	6	20:00	Input	2 400 kW
2	10:00	Output	1 000 kW	7	7:00	Stand-by	0 kW
3	13:00	Output	2 000 kW	8			
4	16:00	Output	1 500 kW	9			
5	18:00	Stand-by	0 kW	10			

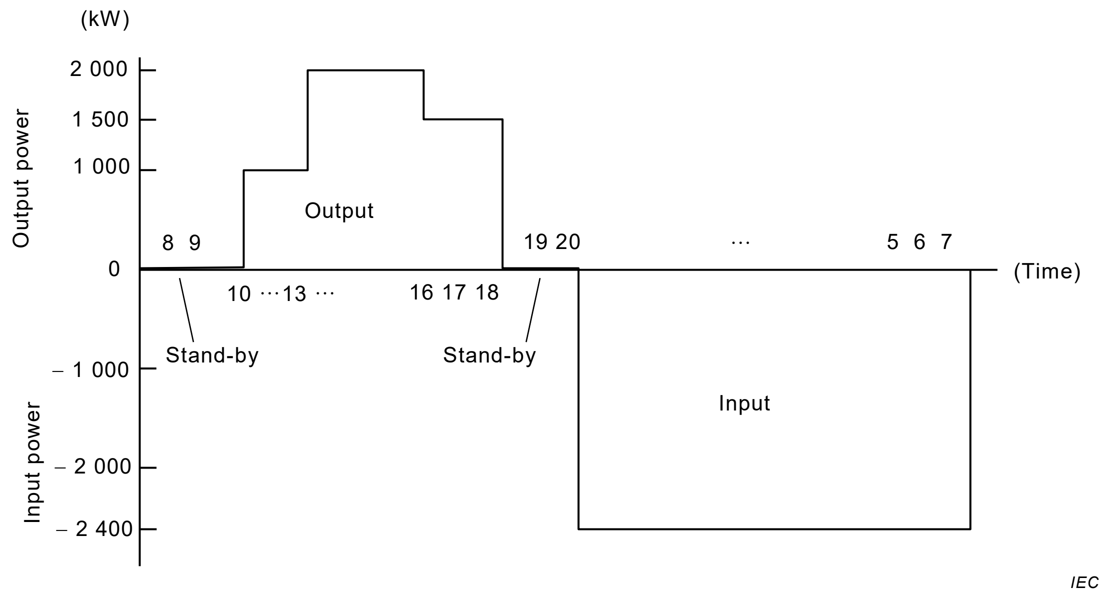
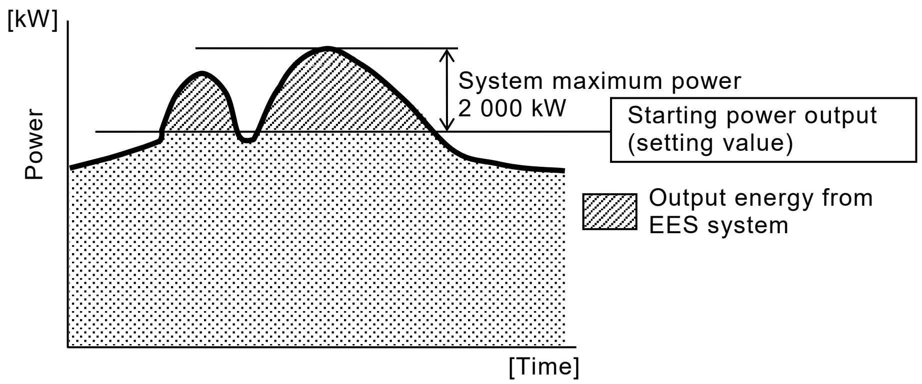


Figure 8 – Example of day pattern operation at primary POC

5.5.8 Automatic load following control

In this operation mode, the electric output power automatically changes according to the load change, for example for peak shaving purpose. An example of a peak shaving application with an EES system providing a maximum power output of 2 000 kW is shown in Figure 9.



NOTE When the load exceeds the setting value, the EES system delivers the power corresponding to the exceeded value.

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Figure 9 – Example of peak shaving application

5.5.9 Power control modes for grid voltage support

5.5.9.1 General

When grid connected, the EES system shall be capable of operating in, for example, one of the following control modes. These different reactive power control modes for grid voltage support are exclusive; only one mode shall be active at a time. Possible control modes, which are described in 5.5.9.2 to 5.5.9.5, are

- constant value control modes
- voltage-related control modes
- active power-related control modes
- voltage-related active power reduction

5.5.9.2 Constant value control modes

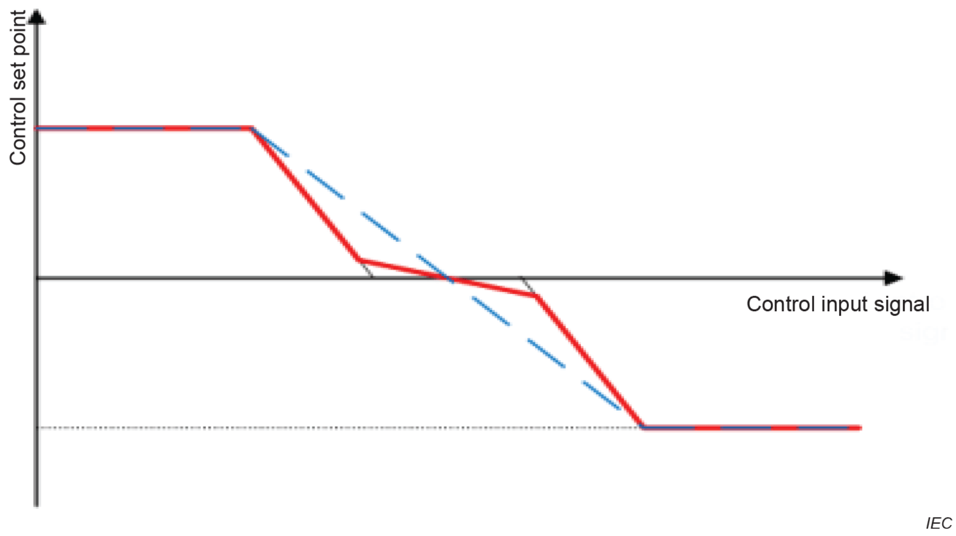
The EES system shall be able to activate two different constant value control modes: Q constant mode and cosφ constant mode. With the activation of one of those two control modes, the EES system shall be able to control the reactive power output or the cosφ of the output according to a set point set in the control of the EES system or by a remote control signal.

5.5.9.3 Voltage-related control modes

The EES system shall be able to activate two different voltage-related control modes: $Q(U)$ and cos$\varphi(U)$. With the activation of one of those two control modes, the EES system shall be able to control the reactive power output or the cosφ of the output, respectively, as a function of the voltage.

For each of these voltage-related control modes, behaviour with a minimum and maximum value and a characteristic according to Figure 10 shall be configurable. In addition to the above-mentioned characteristic, further features and their relative parameters shall be integrated into the EES control system, as follows:

- The dynamics of the control shall be configurable.
- To limit the reactive power at low active power, two methods shall be configurable (these methods are exclusive; only one method may be active at a time):
  - for cos$\varphi(U)$ control mode, an upper and lower limit for cosφ should be configurable (for example, in the range of 0 to 0,95);
  - for $Q(U)$ control mode, the activation and deactivation should be configurable in the active power operating range of the EES system.



NOTE 1 Source for Figure 10: CLC/TS 50549-1 and CLC/TS 50549-2.

NOTE 2 The red, grey and blue curves represent three possible control characteristics.

Figure 10 – Example of a general control characteristic

5.5.9.4 Active power-related control modes

The EES system shall be able to activate two different active power-related control modes: $Q(P)$ and cos$\varphi(P)$. With the activation of one of those two control modes, the EES system shall be able to control the reactive power output or the cosφ of the output as a function of the active power output.

For each of these active power-related control modes, a characteristic with a minimum and maximum value and three connected lines according to Figure 10 shall be configurable.

A change in active power output shall result in a new Q or cosφ set point, defined according to the characteristic. The appropriate response to a new Q or cosφ,set point shall be as fast as possible to allow the change in reactive power to be in line with a possible change in active power.

5.5.9.5 Voltage-related active power reduction

In order to avoid disconnection due to over-voltage protection during active power output or under-voltage protection during active power input, the EES system shall implement a control mode to reduce/increase active power output as a function of voltage variation (over- and low-voltage ride through capability). The activation of such control mode shall not cause steps or oscillations in the output power.

5.6 Communication interface

5.6.1 General

Subclause 5.6 includes recommendations for the communication interface of EES systems.

5.6.2 Information model for an EES system

The reference architecture of an EES system is given in 4.1. An essential requirement for integration of EES systems within electric power systems is the definition of an EES system information model for the communication (see Figure 11). An information model is a fundamental step to get interoperability of EES systems with other devices.

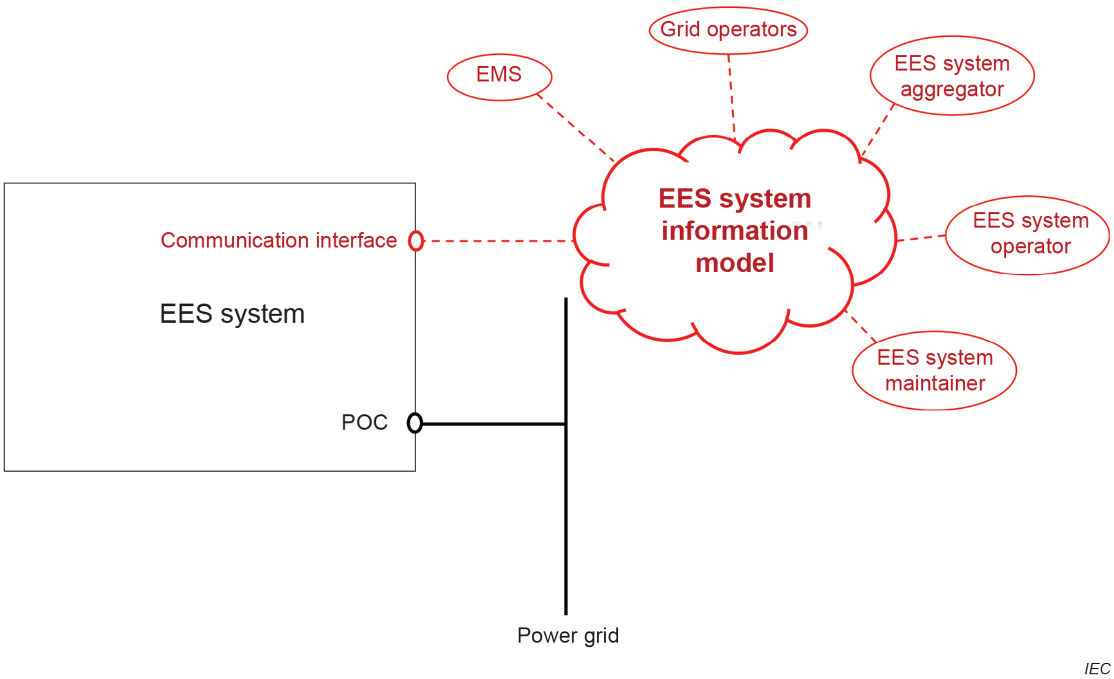


Figure 11 – Reference diagram for information exchange

Another relevant consequence of the use of EES system information modelling for the communication between an EES system and external stakeholders is to offer the possibility of aggregation of EES systems (see Figure 12). One large EES system can be formed by aggregation of several EES systems which are electrically connected to the same POC. In order to evaluate the overall performance of an aggregation of EES systems, the information model of each EES system shall be able to provide information about the parameters' operation status and available functions.

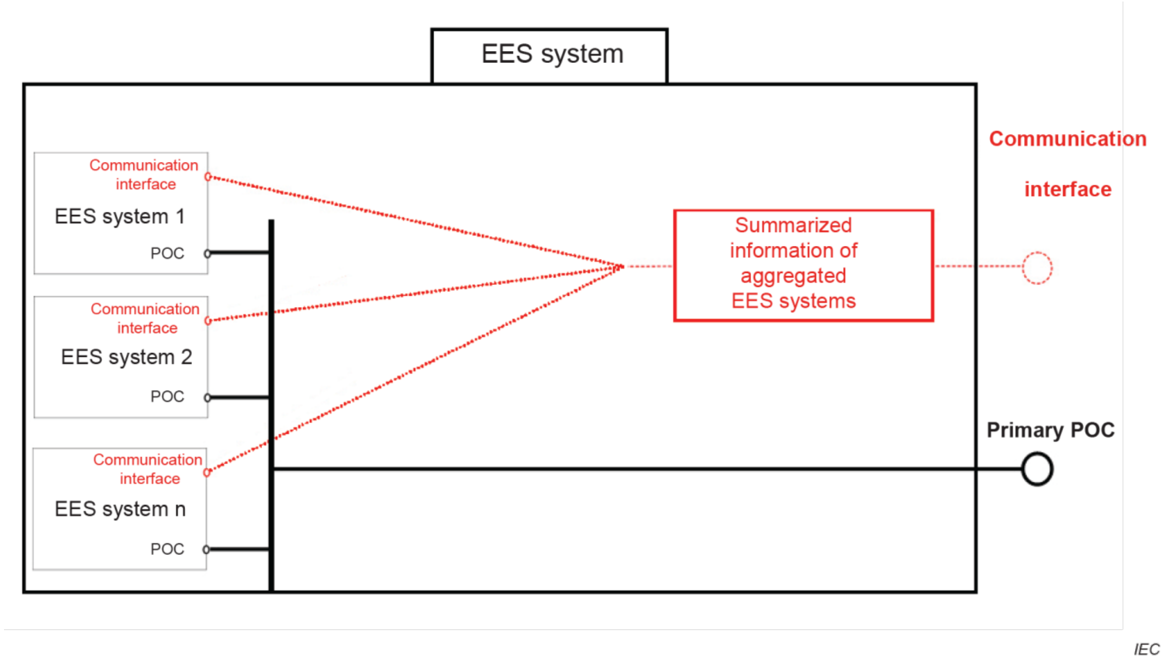


Figure 12 – EES system as an aggregation of several EES systems at the same primary POC

The information model should therefore allow the EES system to:

– provide stakeholders with all the measurements necessary for a secure and reliable operation of the EES system within the power system,

– activate and provide power system operators with ancillary services (active power limitation, provision of reactive power, voltage control, etc.),

– rapidly disconnect the EES system from the grid when required.

To achieve the above purposes, the information model shall at least include the following categories of messages defined according to the type of exchanged information:

- EES system characteristics represent data related to the rated values of a specific EES system which uniquely identify the EES system within the power system.
- EES system status represents information related to the operating and/or physical status of an EES system; the EES system's status can change following events on the network or at the EES system’s site or due to remote control signals.
- EES system measurements represent data related to EES system variables directly measured, or calculated through the elaboration of other measured variables such as voltage or current.
- EES system operating limits represent the limit values to change the EES system's operating range or the set-points/parameters for the use of the EES system's remote control capabilities by stakeholders.
- EES system forecast represents a forecast of the EES system's active and reactive power characteristic for different objectives, with the scope to provide stakeholders with some information for the management of the EES system.
- EES system connection status represents the signals to be exchanged in order to get the connection status (connected or disconnected) of the EES system.

- EES system diagnostics represent the signals to be exchanged in order to inform the stakeholders about the state of health of the EES system, the approach of abnormal operating conditions and/or fault conditions.

In case of a loss of connection of the communication interface with the EES system or a part of the EES system, necessary procedures should be defined in advance.

5.6.3 Remote monitoring and control

5.6.3.1 Categories of EES system for measurement and monitoring

The requirements of monitoring activities and the information to be exchanged have to be developed according to the relevance of the EES system with respect to network operation and to the on-going innovative solutions developed in the framework of Smart Grid initiatives. In accordance with these requirements, it is then possible to define different progressive levels of EES monitoring and control requirements:

- Measurement and monitoring category I: EES systems in this category are not relevant for network operation. EES systems are not required to provide specific monitoring capabilities. The ability to receive signals from the local distribution entity or aggregator may be optional.
- Measurement and monitoring category II: EES systems in this category are unlikely to have a relevant impact on network operation and are usually not included in the power system operator's control algorithms. EES systems in this category shall however provide monitoring capabilities for stakeholders different from the power system operator. The EES system may be configured to receive dispatch instructions or operation requests from the local distribution entity or aggregator.
- Measurement and monitoring category III: EES systems in this category shall provide monitoring capabilities since they have/could have a significant impact on the network to which they are connected. For EES systems of this category, the power system operator is likely to require on-line monitoring of EES status and active and reactive power. The interfacing of the EES system with the system operator's systems requires integration with the scan rate and the protocol currently in use by the operator. An EES system in such category can also be included into the system operator's control algorithms. The EES may be required to receive dispatch instructions or operations requests from the power system operator or local distribution entity or aggregator.

The information to be exchanged between an EES system and the different stakeholders depends on the application, voltage level of connection, the EES system capacity and the criticalities of the local power system. For an EES system, the stakeholders should assess all of these factors to define in which category the EES system may belong. Table 3 provides some guidelines for defining each category and the categories of messages to be included in the information exchange.

Table 3 – Example for messages of measurement and monitoring categories versus categories of messages

Category of messages \ Measurement and monitoring category	I	II	III
EES system characteristics		X	X
EES system status	(X)	X	X
EES system measurements			X
EES system operating limits		X	X
EES system forecast			X
EES system disconnection	(X)	X	X
EES system diagnostics			X

5.6.3.2 Interoperability

Interoperability is the ability of devices to exchange information and work together in a system. The interoperability of an EES system with stakeholders would be achieved by using published object and data definitions, standard commands, and standard protocols (see 5.6.3.3).

Interoperability generally requires time coordination between the transacting parties. The needs in this area depend on the application enabled between parties. Time synchronization can be handled by many mechanisms, ranging from manual entry of time to constant time updates from global positioning system sources.

Issues of cyber security shall be taken into consideration when configuring internal communications and configuring up to and including the point of common coupling.

5.6.3.3 Protocol

Standardized communication should be used for the communication between the EES system and the stakeholders. Common standards used for grid management involving control centres are IEC 60870-5-101, IEC 60870-5-104, IEC 60870-6 (all parts), IEEE Std 1815 (DNP3) or IEC 61850 (all parts).

5.6.3.4 Development of an EES system information model

For each category of messages, Table 4 shows examples of typical single messages which could be exchanged between stakeholders and EES systems. The messages to be actually exchanged between an EES system and the different stakeholders depend on the application, the voltage level of the connection, the EES system capacity and the criticalities of the local power system. Disclosure of the information profile should be defined during the planning phase in order to provide the required data to the different stakeholders. However, the information model should support future integration due to the evolution of the EES system and of the stakeholders' requirements.

Table 4 – Example of messages of an EES system information model

Messages related to EES system characteristics	• EES system name • name of primary POC • nominal voltage at primary POC • EES system control capabilities available – grid frequency regulation – islanding control – manual active power control – pattern active power control – automatic load following control – active power limitation – Q constant value – $Q(U)$ – $Q(P)$ – cosφ constant value – cos$\varphi(U)$ – cos$\varphi(P)$ – $P(U)$ • capability chart at primary POC • EES system rated energy capacity • nominal grid frequency

<table>
<tr>
<td>Messages related to the EES system status</td>
<td>The EES system availability represents the EES system's connection status with respect to the grid:

fully connected,
partially connected (in the case of aggregated EES systems where part of those are disconnected),
disconnected but available for connection,
disconnected and not available for connection,
unavailable (in case of communication failure).

The EES system operating status represents

available energy at present power
available energy at rated power
the EES system's remote control capabilities effectively activated on the EES system, such as

grid frequency regulation
islanding control
manual active power control
pattern active power control
automatic load following control
active power limitation
Q constant value
$Q(U)$
$Q(P)$
cosφ constant value
cosφ (U)
cosφ (P)
$P(U)$

The EES system status with respect to capabilities, such as:

EES system operating on maximum active power limit
EES system operating on minimum active power limit
EES system operating on maximum reactive power limit
EES system operating on minimum reactive power limit

An EES system could provide different operating functions at the same time</td>
</tr>
<tr>
<td>Messages related to EES system measurements</td>
<td>All the measures are intended at the primary POC and the typical measurements to be exchanged are

voltage
current
active power
reactive power
frequency
power factor
total harmonic distortion
auxiliaries consumption
</td>
</tr>
</table>

Messages related to EES system operating limits	This information is not related to the activation/deactivation of EES system operating functions described above (see 5.5) but to the parameterisation of such functions: • frequency control – frequency dead-band – frequency droop coefficient – frequency margin reserve • manual active power control – active power set point • pattern active power control – active power set point curve • automatic load following control – load value • active power limitation – maximum active power set point – minimum active power set point • voltage Q or cosφ constant value control – Q set point – cosφ set point • voltage-related control – $Q(U)$ characteristic curve – cosφ (U) characteristic curve
Messages related to EES system forecast	Represent a forecast of EES system capability curves for different objectives, with the scope to provide stakeholders with some information for management of the EES system. The different objectives of the request could be: • time • active power • final state of charge
Messages related to EES system connection status	The messages to be exchanged shall cover the following aspects: • request from stakeholders to disconnect the EES system, • communication by the EES system that the EES system has been disconnected, • information from stakeholders that the disconnection is no longer required and that the EES system could therefore be re-connected to the network
Messages related to EES system diagnostics	• Warning/alarms that refer to environmental conditions (temperature, humidity, pressure,etc.). • Warning/alarms that refer to operation (current, voltage, power, state of charge, etc.). • Warning/alarms that refer to safety (electrical isolation, smoke detection, gas emissions, etc.). • State of protection systems (EES system and/or single equipment within EES system, etc.). • Warning/alarms that refer to auxiliary equipment (conditioning, auxiliary power supply, etc.). • Warning/alarms that refer to security (enclosure integrity, movement detection, etc.).

6 EES system performance assessment

6.1 Factory acceptance test (FAT)

Pre-assembly in the factory of combined devices to a subsystem of an EES system may be done. In this case a FAT of this subsystem may be useful.

FAT methods, FAT items and FAT acceptance criteria should be discussed between the EES system supplier and EES system owner on the basis of IEC 62933-2-1. A FAT protocol will be prepared by the system supplier for user approval beforehand.

FAT results should be sent prior to the transportation of the EES system to the site.

The FAT results shall be provided to the EES system owner and be considered with the site acceptance test (SAT).

6.2 Installation and commissioning

6.2.1 General

During the installation and commissioning phases it is necessary to validate the requirements of

- the EES system environment (see 5.2)
- the main electrical system parameters (see 5.4)
- the functional system performance (see 5.5)
- the communication interface (see 5.6)

6.2.2 Installation phase

The installation phase of an EES system can be subdivided into two phases: transportation and site-assembling. Examples of items to be taken into account are shown in Table 5.

For detailed examples regarding EES system installation, see Annex B.

Table 5 – Example of items to be taken into account in the different installation phases

Regulation	Transportation	Site-assembling
Electrical	Transportation regulation in land, sea, air and warehousing.	Confirmation of earthing Measurement of insulation resistance
Chemical		Confirmation of fire prevention and fighting Confirmation of alarms and indications
Mechanical		Foundations Dimensional measurement and appearance check

6.2.3 Commissioning phase

6.2.3.1 General

After completion of the installation phase and during the commissioning phase the system supplier should make sure that the EES system meets the performance requirements and system specification. Afterwards the site acceptance test may be performed (see 6.3).

Generally both the factory acceptance test (FAT) and site acceptance test (SAT) demonstrate system compliance with EES system specifications.

In the commissioning phase, the performance parameters of the EES system should be measured by appropriate testing methods and procedures in order to confirm that system functions and capabilities are implemented as designed.

During the planning and commissioning phase, system security and safety shall be taken into consideration which includes both physical and cyber security. Existing standards shall be used, for example IEC 62351 (all parts), IEC 62443 (all parts), IEC TS 62933-5-1 and ISO/IEC 27000.

The main performance test items at the commissioning phase are described in Table 6. Their evaluation methods shall be selected from IEC 62933-2-1.

Table 6 – Points of attention for commissioning phase

Energy capacity values	Input and output power values	Round trip efficiency	End-of-service life values	Response time parameters
Measurement of input and output energy capacity (initial, rated)	Rated input and output power test Rated output power test for on-grid and off-grid use	Measurement of self-consumption / self-discharge	— (Recording of relevant initial parameters)	Measurement of response time (for autonomous operation, load-following operation, scheduled operation and remote dispatch) Measurement of response time from standby state to start up Measurement of response time from charging state to discharging state

For measurements, monitoring, information exchange, and control of the EES system see 5.6.

6.2.3.2 Insulation performance

6.2.3.2.1 Insulation resistance

The insulation resistance between the parts to be energized, such as the primary subsystems of the EES system and the earthing, should be determined appropriately in accordance with the maximum operating voltage.

6.2.3.2.2 Dielectric strength

The EES system's insulation should be verified by the dielectric strength test to ensure performance standards are met – both in the FAT and SAT. The proper test voltage should be applied continuously between the parts to be energized and the earthing in this test. In addition, the EES system, which operates at a different temperature from the normal temperature, should be tested at the operating temperature.

6.3 Site acceptance test (SAT)

The performance of the commissioned EES system, which may be a combination of devices and/or prefabricated subsystems, should be confirmed in the SAT.

The SAT should be done as shown in IEC 62933-2-1. The SAT can be conducted by dividing into several stages according to the installation environment, but it is also necessary to confirm the performance of the main functions of the whole EES system. SAT criteria should previously be determined between the EES system supplier and the EES system owner.

Constraints between power rating, available energy, ambient conditions and other internal/external factors shall be indicated by the system supplier.

Some test items can be difficult or practically impossible to check at the site due to the scale of the whole system or environmental restrictions. In such cases, some items of the site acceptance tests may be replaced by factory acceptance tests. Site acceptance tests may be conducted for subsystems and some of the site acceptance tests may be combined with some of the factory acceptance tests and results reviewed by analysis. It is necessary to keep the documents as complete records, to prepare the operation manual of the system and the tracking records including the examination (FAT, SAT) results before completion of the system installation.

6.4 Performance monitoring phase

In the performance monitoring phase (see Table 7), the performance parameters of the EES system shall be measured and monitored by appropriate methods and procedures such as those shown in the IEC 62933-2-1. Alternatively, methods and procedures agreed between users and system suppliers are acceptable as long as they follow specified practices. Performance degradation in system functions and ageing capabilities should be monitored and evaluated periodically.

Table 7 – Points of attention for performance monitoring phase

Energy capacity values	Input and output power values	Round trip efficiency	End-of-service life values	Response time parameters
Measurement of actual energy capacity Measurement of actual input and output energy capacity (as required) Measurement of actual back-up energy capacity (as required)	Performance verification of input and output power (rated and/or short duration capabilities) Load-following power test for on-grid and off-grid use	Historical records of daily or weekly efficiency Historical records of power consumption in auxiliary and control subsystems Historical records of self-consumption of EES system and/or self-discharge of accumulation subsystem	Evaluation of performance parameters, whether their specified values are kept (i.e. still being in service life)	Performance verification of response time Start and stop test (as required)

Local measurement and monitoring data collected during the SAT and during the commissioning phase may be used for comparison with periodic tests performed on the EES system (see Table 8). Energy metering devices at the auxiliary and primary POC may also be provided locally for proper accounting of energy data.

Table 8 – Example of local measurements and monitoring of EES system

Subsystem (where)	**Measure** (what)	**Sample time** (how often)	**Term data storage** (how long)
Accumulation subsystem	State of charge of different units	≤ 1 min	≥ 1 d
	Physical or electrical parameters (temperature, pressure, voltage, etc.)	≤ 1 min	≥ 1 d
Power conversion subsystem	Electrical parameters: Voltage Current Active power Reactive power Frequency Power factor Total harmonic distortion	Related to the application of EES system	≥ 1 d
Connection subsystem	Voltage Current Active power Reactive power Frequency Power factor Total harmonic distortion Status of breakers/switches		≥ 1 d
Auxiliary subsystem	Active power Power factor Energy consumption	≤ 1 min 15 min Average	≥ 1 d ≤ 1 year
Control subsystem	Reference Environmental measures Safety measures	1 min	1 week

Annex A
(informative)

Examples of EES system applications

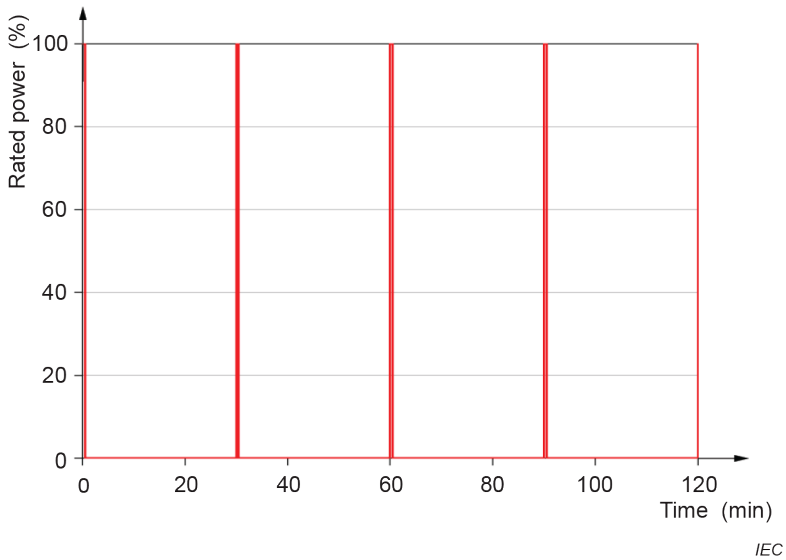
A.1 EES system designed for reserve control

A.1.1 General

An EES system can be designed to reduce fossil fuels consumption when a genset assumes the primary reserve. The different aspects to take into account (economical, ecological, asset management, etc.) are under the responsibility of the local electrical network planner. To estimate them, the planner should have an estimation of the cost of investment (CAPEX) and the operational cost (OPEX), including the performance evolution through the life time of the EES system, and the possible savings. This can be achieved by avoiding other investments and operational costs in other assets (transmission, distribution, generation).

A.1.2 Example of an EES system for primary frequency control

An EES system used in a frequency control application should be able to handle a primary frequency control situation during a sudden loss of generation or during a sudden loss of load. For example an EES system can provide for 30 s the active (short term) rated power, rest for 29,5 min (see Figure A.1), and then can repeat this same pattern of use over a period of 2 h or to a point in time when the low SOC limit of the EES system is reached. In case of a sudden loss of generation, typical values of a required duty cycle are given in Table A.1 and typical values of recovery time for primary frequency control are given in Table A.2. For primary frequency control the initial SOC may be set at maximum SOC for sudden loss of generation, and at minimum SOC for sudden loss of load.



NOTE Source for Figure A.1: PNNL-22010.

Figure A.1 – Sample duty cycle for a primary frequency control application with 30-s power output every 30 min shown over 2 h

Table A.1 – Sample values of a duty cycle for primary frequency control for sudden loss of generation

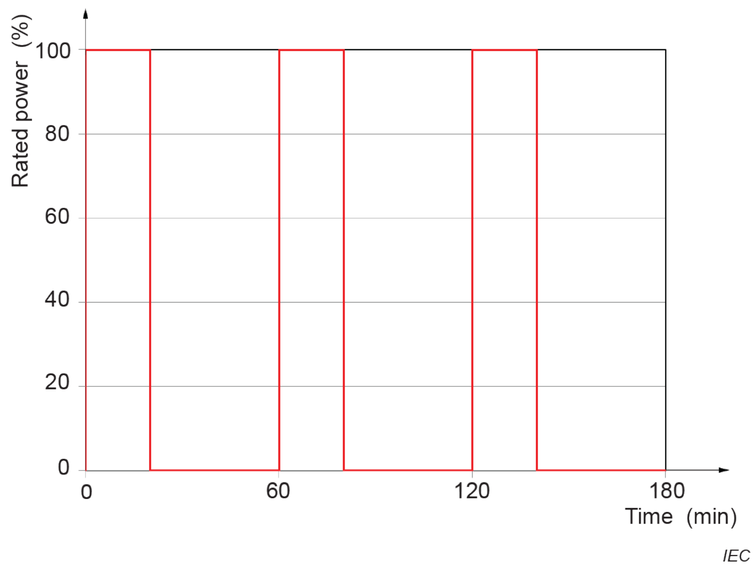
Overall duration	2 h
Initial energy content	SOC = 100 %
Energy content value at the end of the duty cycle	SOC ≥ 0 %
Maximum value of active output power	100 % of (short term) rated power
Maximum value of active input power	n.a (loss of load is not considered)
Speed of change of active power values	4/h
Speed of change between input or output power	n.a (loss of load is not considered)
Maximum partial energy output	ΔSOC ≈20 %
Maximum partial energy input	n.a (loss of load is not considered)
Maximum value of reactive output power	n.a.
Maximum value of reactive input power	n.a.
Speed of change of reactive power values	n.a.
Speed of change between reactive input and output power	n.a.

Table A.2 – Sample values of recovery time for primary frequency control for sudden loss of generation

Duration	12 h
Range of allowed active output power	n.a.
Range of allowed active input power	100 % of (short term) rated power
Range of allowed reactive output power	n.a.
Range of allowed reactive input power	n.a.
Maximum allowed ramp rates of active and reactive power	50 % of rated power/s
Allowed range of power factor values at primary POC	n.a.

A.1.3 Example of an EES system for secondary frequency control

In an example of secondary frequency control situation, an EES system can provide output power continuously for 20 min, rest for 40 min, and then repeat this same pattern of use over a period of 3 h or to a point in time when the low SOC limit of the EES system is reached (see Figure A.2 and Table A.3). Both scenarios – power output (at sudden loss of generation) and power input (at sudden loss of load) – may be considered. The initial SOC may be set at maximum SOC for sudden loss of generation, and at minimum SOC for sudden loss of load.



NOTE Source for Figure A.2: PNNL-22010.

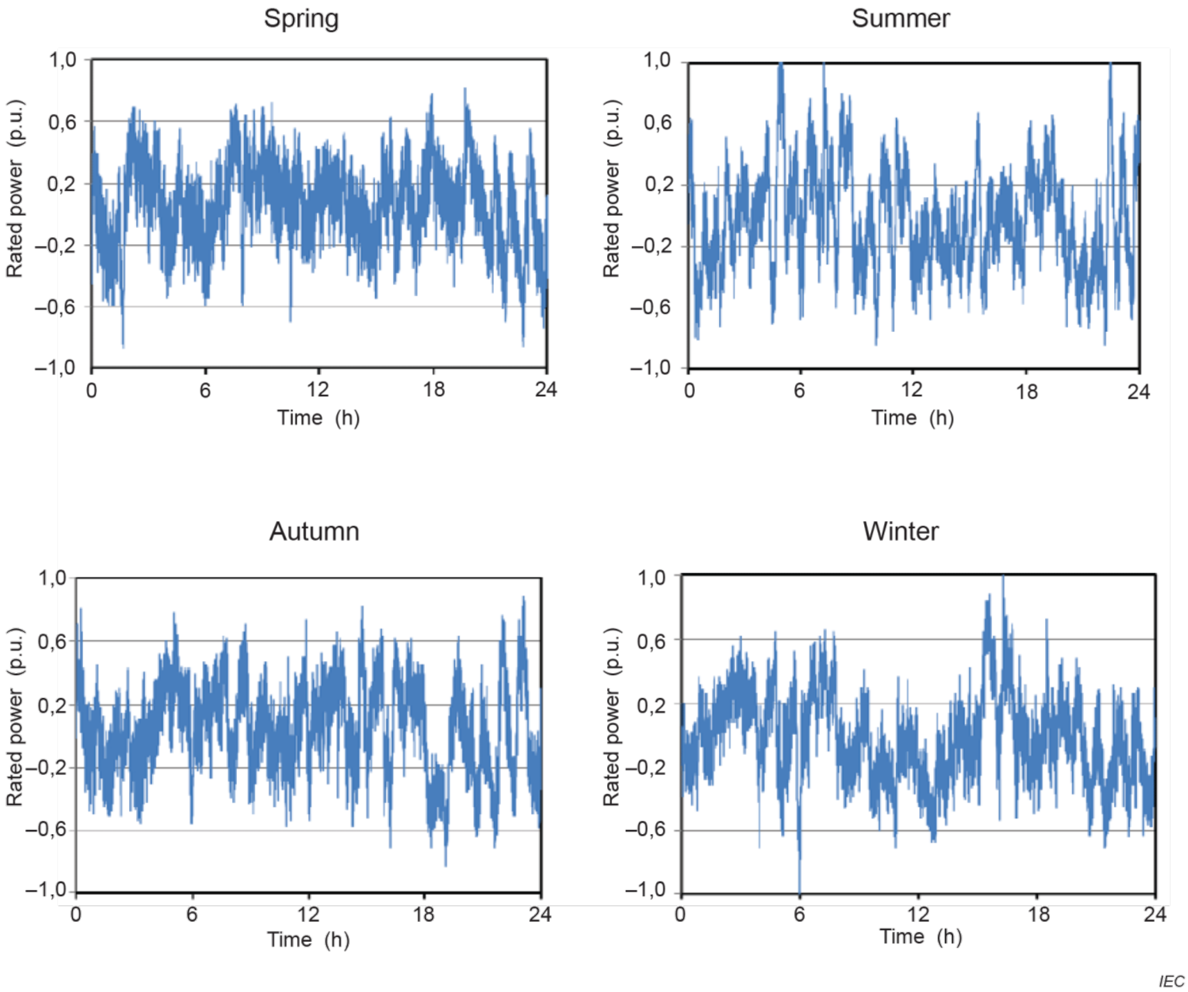
Figure A.2 – Sample power output for a secondary frequency control application with 20-min power output over 3 h

Table A.3 – Sample values of a duty cycle for secondary frequency control for sudden loss of generation

Overall duration	3 h
Initial energy content	SOC = 100 %
Energy content value at the end of the duty cycle	SOC ≥ 0 %
Maximum value of active output power	100 % of rated power
Maximum value of active input power	n.a (loss of load is not considered)
Speed of change of active power values	2/h
Speed of change between active input or output power	n.a (loss of load is not considered)
Maximum partial energy output	ΔSOC ≈33 %
Maximum partial energy input	n.a (loss of load is not considered)
Maximum value of reactive output power	n.a.
Maximum value of reactive input power	n.a.
Speed of change of reactive power values	n.a.
Speed of change between reactive input and output power	n.a.

A.1.4 Example of an EES system for dynamic frequency control

In an example of dynamic frequency control applications the grid frequency data can be obtained for four seasons from a utility. With a strategy similar to Figure 6, the input and output power of an EES system can be derived (see Figure A.3). In the example power is normalized. Since the duty cycle corresponds to both charge and discharge, the initial SOC should be set far enough away from the maximum or minimum limit so that these limits are not breached during operation. It is assumed that the initial SOC is set at 50 % for dynamic frequency support. Table A.4 contains the sample values of a duty cycle for dynamic primary frequency control.



NOTE Source for Figure A.3: PNNL-22010.

Figure A.3 – Sample output power of an EES system for a dynamic frequency control application in spring, summer, autumn and winter

Table A.4 – Sample values of a duty cycle for dynamic primary frequency control

Overall duration	24 h
Initial energy content	SOC = 50 %
Energy content value at the end of the duty cycle	SOC ≥ 20 %
Maximum value of active output power	100 % of rated power
Maximum value of active input power	100 % of rated power
Speed of change of active power values	continuously changing
Speed of change between active input or output power	up to maximum ramp rate of the EES system
Maximum partial energy output	ΔSOC = 30 %
Maximum partial energy input	ΔSOC = 30 %
Maximum value of reactive output power	n.a.
Maximum value of reactive input power	n.a.
Speed of change of reactive power values	n.a.
Speed of change between reactive input and output power	n.a.

A.2 EES system in conjunction with renewable energy production

A.2.1 General

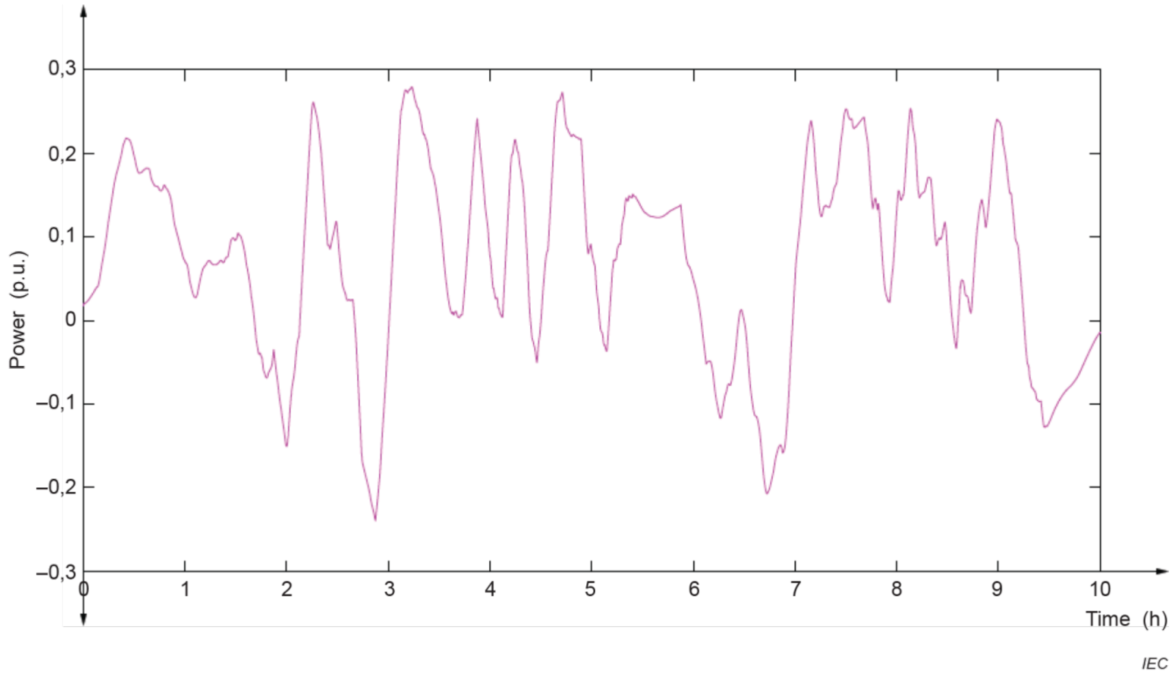
The EES system may be used to manage the intermittence of renewable energy production. EES systems can smooth intermittency and support grid stability, as well as store the excess production to assist with peak shaving.

For the first application, the EES system should have the capability to store a relatively small amount of energy, and response time should be short. For the second application, the EES system should have the capability to store a large amount of excess production energy but the response time required should be varied, depending on the different time scales' peak shaving objectives (for example short term, medium term or long term peak shaving).

In both cases the input/output power and the energy storage capabilities of the EES system should be designed based on different application purposes and energy storage equipment types. Meanwhile, all the major characteristics of the EES systems should be taken into account.

A.2.2 Example of EES system for renewable (energy) firming

EES systems may be used in renewable (energy) firming applications. Renewable (energy) firming is the use of an EES system to balance renewable power generation over a given time period, for example over one hour. That is, the amount of energy generated by the renewable energy source over each hour (or the average power over one hour) may be guaranteed to be a fixed amount (within a pre-determined range). In the case of over-generation of power during the hour, the EES system takes up the excess energy generated by getting charged via the power input. During periods of under-generation, the EES system provides the power deficit by discharging via power output. Figure A.4 shows a sample power curve of an EES system for firming up photovoltaic generation. The difference between the moving average and the target energy value over the hour determines the power input or output of the EES system. The power values are normalized with respect to the rated power of the EES system, where a positive sign represents the power input of the EES system and a negative sign represents the power output from the EES system as a function of time in hours. Sample values of a duty cycle for a renewable (energy) firming application are given in Table A.4.



NOTE Source for Figure A.4: PNNL-22010.

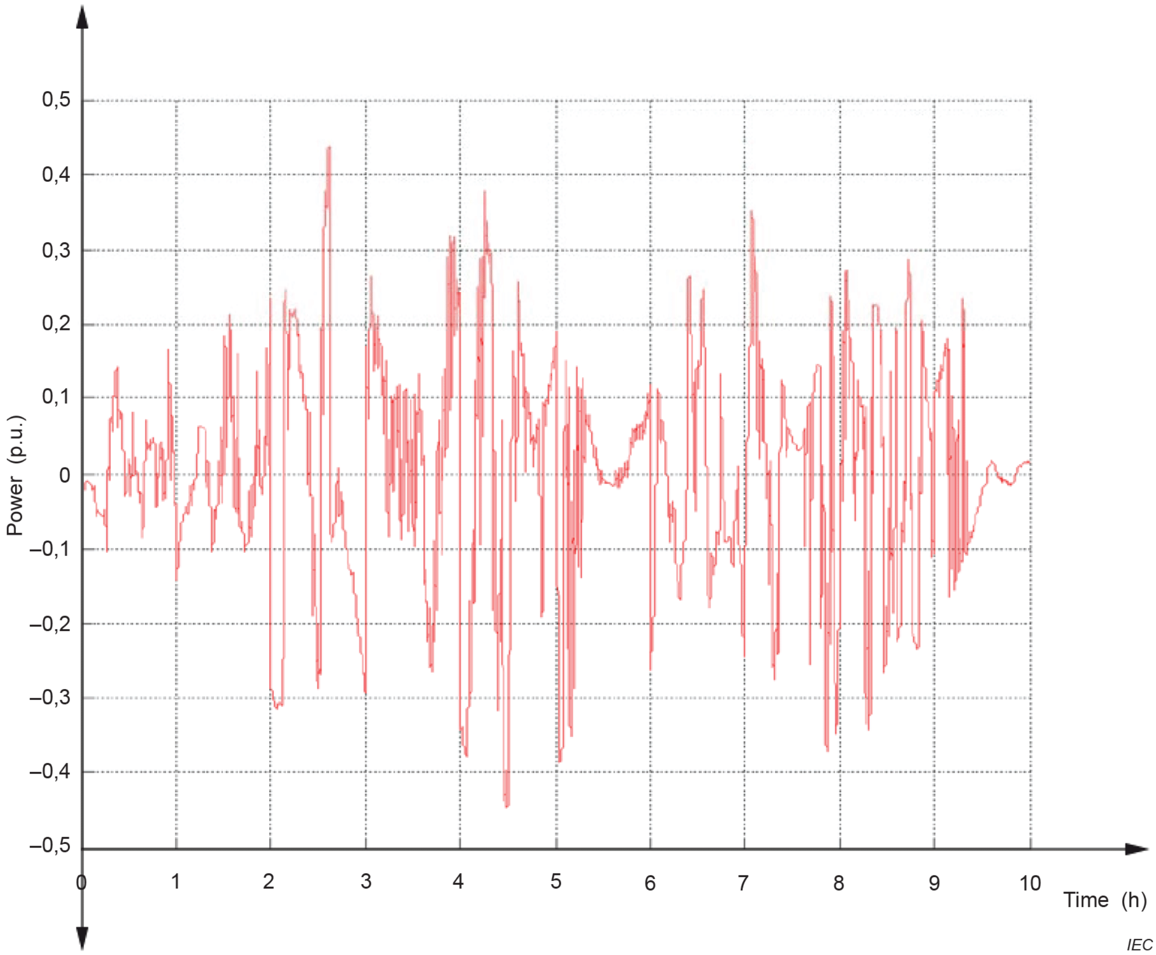
Figure A.4 – Sample output power of an EES system in a renewable (solar) energy firming application

Table A.4 – Sample values of a duty cycle for renewable (energy) firming

Overall duration	12 h
Initial energy content	SOC = 70 %
Energy content value at the end of the duty cycle	SOC = 40 %
Maximum value of active output power	100 % of rated power
Maximum value of active input power	100 % of rated power
Speed of change of active power values	continuously changing
Speed of change between active input or output power	≤ 3 per hour
Maximum partial energy output	ΔSOC=40 %
Maximum partial energy input	ΔSOC=45 %
Maximum value of reactive output power	n.a.
Maximum value of reactive input power	n.a.
Speed of change of reactive power values	n.a.
Speed of change between reactive input and output power	n.a.

A.2.3 Example of EES system for renewable (power) smoothing

Renewable (power) smoothing is the use of an EES system to mitigate rapid fluctuations in the variable power output of renewable energy sources. For example, the EES system is used to absorb or supply power at appropriate times as determined by a control system, resulting in a less variable composite power signal at feeder and/or transmission level. Figure A.5 shows a sample power curve of an EES system for smoothing photovoltaic power generation. The difference between the moving average and the target power value determines the power input or output of the EES system. The power values are normalized with respect to the rated power of the EES system, where a positive sign represents the power input of the EES system and a negative sign represents the power output from the EES system as a function of time in hours.



NOTE Source for Figure A.5: PNNL-22010.

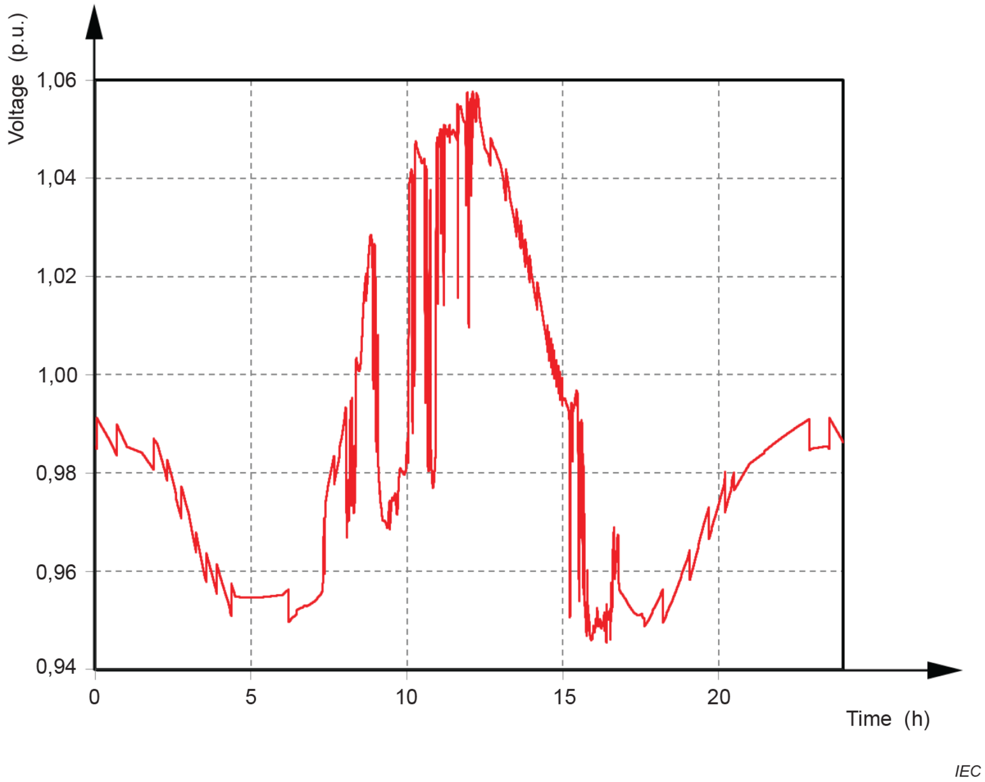
Figure A.5 – Sample output power of an EES system for a renewable (solar) power smoothing application

A.3 EES system for grid support applications

A.3.1 Example of an EES system for grid voltage support ($Q(U)$ control mode)

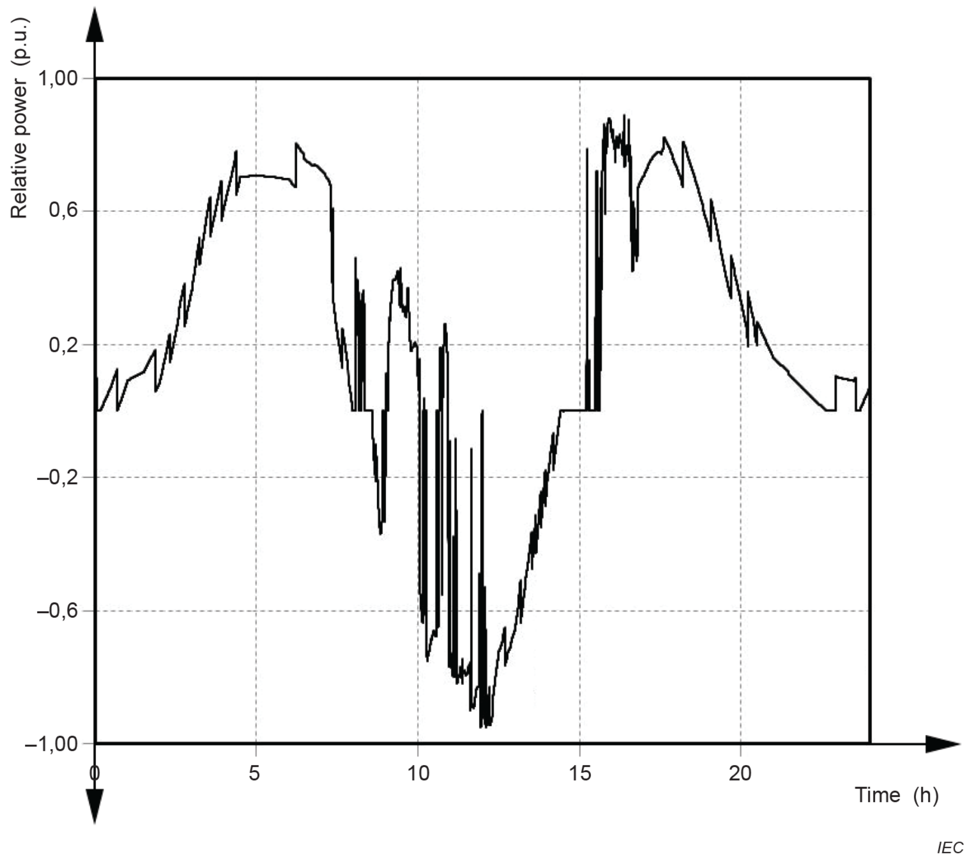
As described in 5.5.9.3 an EES system may support the grid voltage by providing or absorbing reactive power at the POC. In the planning phase it should be taken into account that the EES system may not be able to provide its rated reactive power at the lower end of the grid voltage at the POC. Since it is not clear whether this applies to all power conversion systems, the power value may be normalized with respect to the lowest value of the maximum reactive power available across the range of the grid voltage being considered. For example the lowest and highest grid voltages for $Q(U)$ control mode are set at 0,94 and 1,06 times the nominal voltage at the POC, respectively. Grid voltage support by $Q(U)$ control mode involves providing or absorbing reactive power based on grid voltage conditions. Assuming the EES system is doing only grid voltage support by $Q(U)$ control mode, the full rated power of an EES system could be used for this application.

The general control characteristic of the voltage-related control mode $Q(U)$ is depicted in Figure 10. In the example in A.3.1 the reactive power Q of the EES system varies linearly between 0 p.u. and 1 p.u. for grid voltage U at the POC between 0,99 p.u. to 0,94 p.u. and between 1,01 to 1,06 p.u. The reactive power of the EES system was set to 0 p.u for 0,99 p.u. < grid voltage U < 1,01 p.u. Applying such a characteristic to the sample grid voltage at the POC (shown in Figure A.6) the EES system provides or absorbs the reactive power depicted in Figure A.7. It can be seen that the maximum voltage is close to 1,06 p.u. and the minimum is close to 0,94 p.u.



NOTE Source for Figure A.6: PNNL-22010.

Figure A.6 – Example of grid voltage at the POC of a photovoltaic power plant



NOTE Source for Figure A.7: PNNL-22010.

Figure A.7 – Sample reactive power supply of an EES system at the POC

Sample values of a duty cycle for grid voltage support by $Q(U)$ control mode are given in Table A.5. Since it is assumed that there is no exchange of active power between the EES system and the electrical grid (only power losses), there is no constraint on the initial SOC. Although the SOC is not expected to change much, losses can reduce the energy content of the EES system, and the SOC at the end of the duty cycle may be lower.

Table A.5 – Sample values of a duty cycle for grid voltage support by $Q(U)$ control mode

Overall duration	24 h
Initial energy content	SOC = 50 %
Energy content value at the end of the duty cycle	SOC = 47 % (due to losses)
Maximum value of active output power	0 (no significant active power exchange)
Maximum value of active input power	0 (no significant active power exchange)
Speed of change of active power values	n.a.
Speed of change between active input or output power	n.a.
Maximum partial energy output	n.a.
Maximum partial energy input	n.a.
Maximum value of reactive output power	100 % of rated power
Maximum value of reactive input power	100 % of rated power
Speed of change of reactive power values	maximum ramp rate for reactive power
Speed of change between reactive input and output power	maximum ramp rate for reactive power

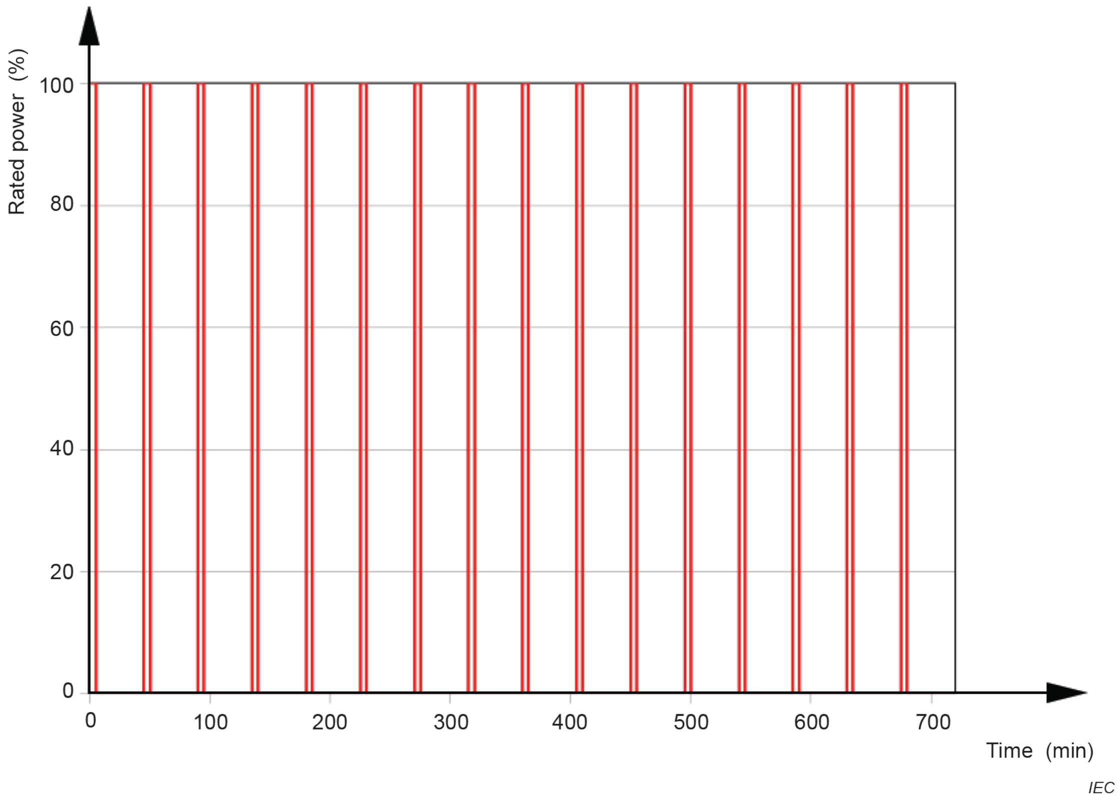
A.3.2 Example of an EES system for power quality support by voltage-related active power injection

As described in 5.5.9.5 a voltage-related active power reduction can be suitable to avoid the disconnection of the EES system from the electrical grid. Similarly EES systems can mitigate voltage sags by injecting active power for up to a few tens of seconds, since a sag or interruption in voltage can cause power disturbances that negatively impact the power quality. This problem may be more common in electrical distribution systems. This application also only considers the ability of an EES system to provide enough energy for customers to ride through a power outage not exceeding 10 min duration, for example. In this case the duty cycle may consist of a continuous output of rated power, for example for 1 min, 5 min and/or 10 min. During this/these duty cycle(s) the active power output of the EES system ramps up to the specified power and stays there for the specified duration. In Table A.6 and Figure A.8 a sample duty cycle of an EES system is described and shown with a 5-min power output of the EES system every 45 min over 12 h. At the end of the application of each duty cycle the EES system shall be brought back to its initial SOC.

In the sizing and planning phase the SOC range for each duty cycle should be determined. Since the power quality support by the voltage-related active power injection involves the power output of the EES system, the starting SOC value can be as high as 100 %, with the lower limit at 0 %. Some EES systems can have a higher starting SOC to ensure the EES system can provide peak power at the lower limit of the SOC range.

Table A.6 – Sample values of a duty cycle for power quality

Overall duration	12 h
Initial energy content	SOC = 100 %
Energy content value at the end of the duty cycle	SOC=0 %
Maximum value of active output power	100 % of rated power
Maximum value of active input power	n.a.
Speed of change of active power values	2 to 4
Speed of change between active input or output power	n.a.
Maximum partial energy output	ΔSOC = 100 %
Maximum partial energy input	n.a.
Maximum value of reactive output power	n.a.
Maximum value of reactive input power	n.a.
Speed of change of reactive power values	n.a.
Speed of change between reactive input and output power	n.a.



NOTE Source for Figure A.8: PNNL-22010.

Figure A.8 – Sample duty cycle for power quality support by voltage-related active power injection with 5-min power output every 45 min over 12 h

Annex B
(informative)

Aspects to be considered with regard to EES system installation

B.1 Site-assembling

In order to maintain the designed performance of EES systems, installation environment should be taken into account: for example, the mechanical aspects of the foundations, substrates and situation, the electrical aspects of the grid-connected facility, and ambient environmental aspects, such as temperature, humidity, atmospheric pressure and lightning, and salt damage.

B.2 Protection against disaster – Fire prevention

In case of installation of an EES system, fire prevention measures such as proper building materials, fire prevention damper and ventilation equipment, gas detectors, heating, ventilation and air conditioning (HVAC), etc., should be taken in conformity with local regulations and depending on installation conditions such as location, structure and scale of the EES system. Especially for gas and fine powder generated from the battery, the detection and exhaust equipment should be installed to mitigate these hazards.

Fire-fighting systems and alarm systems should be equipped in conformity with related regulations and depending on installation conditions such as location, structure and scale of the EES system. Especially for substances that are difficult to be extinguished, dedicated fire fighting equipment and fire prevention measures shall be considered.

B.3 Transportation and on-site storage

The transportation phase of an EES system can be subdivided into in three phases: loading, transport and warehousing. During these three phases it should be assured that designed performance is maintained, deterioration of the EES system is avoided and influence on the environment is minimized. Damage to the EES system can be caused by vibration, temperature and moisture, air pressure. Means to monitor the duration of warehousing (such as temperature indicators, vibration tilt, etc.) could be considered to record the impact on the EES system during this phase.

When transporting the EES systems, the transportation method and packing shall follow national and other relevant regulations.

Bibliography

The following documents provide additional information regarding electrical energy storage and electrical energy storage system.

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

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

PNNL-22010 Rev.1, *Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems*

The following documents provide additional information regarding testing and environmental conditions.

IEC 60068-2 (all parts), *Environmental testing – Part 2-X: Tests*

IEC 60068-3-3, *Environmental testing – Part 3-3: Guidance – Seismic test methods for equipments*

IEC 60721-1, *Classification of environmental conditions – Part 1: Environmental parameters and their severities*

IEC 60721-2-2, *Classification of environmental conditions – Part 2-2: Environmental conditions appearing in nature – Precipitation and wind*

IEC 60721-2-4, *Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Solar radiation and temperature*

IEC 60721-3-3, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 3: Stationary use at weatherprotected locations*

The following documents provide additional information regarding electrical installation.

IEC 60038, *IEC standard voltages*

IEC 60071-1, *Insulation co-ordination – Part 1: Definitions, principles and rules*

IEC 60364 (all parts), *Low-voltage electrical installations*

IEC 60364-1, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 60364-4-41, *Low-voltage electrical installations – Part 4-41: Protection for safety – Protection against electric shock*

IEC 60364-4-42, *Low-voltage electrical installations – Part 4-42: Protection for safety – Protection against thermal effects*

IEC 60364-4-43, *Low-voltage electrical installations – Part 4-43: Protection for safety – Protection against overcurrent*

IEC 60364-4-44, *Low-voltage electrical installations – Part 4-44: Protection for safety – Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-5-51, *Electrical installations of buildings – Part 5-51: Selection and erection of electrical equipment – Common rules*

IEC 60364-5-52, *Low-voltage electrical installations – Part 5-52: Selection and erection of electrical equipment – Wiring systems*

IEC 60364-5-53, *Electrical installations of buildings – Part 5-53: Selection and erection of electrical equipment – Isolation, switching and control*

IEC 60364-5-54, *Low-voltage electrical installations – Part 5-54: Selection and erection of electrical equipment – Earthing arrangements and protective conductors*

IEC 60364-7-712, *Low voltage electrical installations – Part 7-712: Requirements for special installations or locations – Solar photovoltaic (PV) power supply systems*

CLC/TS 50549-1, *Requirements for generating plants to be connected in parallel with distribution networks – Connection to a LV distribution network above 16 A*

CLC/TS 50549-2, *Requirements for generating plants to be connected in parallel with distribution networks – Connection to a MV distribution network*

The following documents provide additional information regarding EMC (electromagnetic compatibility).

IEC 61000-2-2, *Electromagnetic compatibility (EMC) – Part 2-2: Environment – Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems*

IEC 61000-3-2, *Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)*

IEC 61000-3-3, *Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection*

IEC TR 61000-3-6, *Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems*

IEC TR 61000-3-7, *Electromagnetic compatibility (EMC) – Part 3-7: Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems*

IEC 61000-3-11, *Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤ 75 A and subject to conditional connection*

IEC 61000-3-12, *Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase*

IEC TR 61000-3-13, *Electromagnetic compatibility (EMC) – Part 3-13: Limits – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems*

IEC TR 61000-3-14, *Electromagnetic compatibility (EMC) – Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems*

IEC 61000-6-1, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity standard for industrial environments*

IEC 61000-6-3, *Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments*

IEC 61000-6-4, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

IEC 61000-6-5, *Electromagnetic compatibility (EMC) – Part 6-5: Generic standards – Immunity for equipment used in power station and substation environment*

The following documents provide additional information regarding control technology and communication security of EES systems.

IEC 60050-351, *International Electrotechnical Vocabulary (IEV) – Part 351: Control technology*

IEC 60050-447, *International Electrotechnical Vocabulary (IEV) – Part 447: Measuring relays*

IEC 60870-5-101, *Telecontrol equipment and systems – Part 5-101: Transmission protocols – Companion standard for basic telecontrol tasks*

IEC 60870-5-104, *Telecontrol equipment and systems – Part 5-104: Transmission protocols – Network access for IEC 60870-5-101 using standard transport profiles*

IEC 60870-6 (all parts), *Telecontrol equipment and systems – Part 6-X: Telecontrol protocols compatible with ISO standards and ITU-T recommendations*

IEC 61850 (all parts), *Communication networks and systems for power utility automation*

IEEE Std 1815-2012, *IEEE Standard for Electric Power Systems Communications – Distributed Network Protocol (DNP3)*

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