IEC 62282-8-201

Edition 2.0 2024-07
REDLINE VERSION

INTERNATIONAL STANDARD

colour inside

Fuel cell technologies –
Part 8-201: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of power-to-power systems

IEC 62282-8-201:2024-07 RLV(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FUEL CELL TECHNOLOGIES –

Part 8-201: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of power-to-power systems

FOREWORD

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8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at https://patents.iec.ch. IEC shall not be held responsible for identifying any or all such patent rights.

This redline version of the official IEC Standard allows the user to identify the changes made to the previous edition IEC 62282-8-201:2024. A vertical bar appears in the margin wherever a change has been made. Additions are in green text, deletions are in strikethrough red text.

IEC 62282-8-201 has been prepared by IEC technical committee 105: Fuel cell technologies. It is an International Standard.

This second edition cancels and replaces the first edition published in 2020. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) consideration of systems connected to hydrogen supply infrastructure (hydrogen grids, vessels, caverns or pipelines);
b) hydrogen input and output rate is added in the system parameters (5.10);
c) electric energy storage capacity test is revised (6.2);
d) roundtrip electrical efficiency test is revised (6.5);
e) hydrogen input and output rate test is added (6.6.6).

The text of this International Standard is based on the following documents:

Draft	Report on voting
105/1034/FDIS	105/1050/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62282 series, published under the general title *Fuel cell technologies*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document 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

This part of IEC 62282 specifies performance evaluation methods for electric energy storage systems using hydrogen that employ electrochemical reactions both for water~~/~~ and steam electrolysis and electric power generation.

NOTE Heat generation can be a secondary purpose.

This document is intended for power-to-power systems which typically employ a set of electrolyser and fuel cell, or a reversible cell for devices of electric charge and discharge.

A typical target application of the electric energy storage systems using hydrogen is in the class of energy intensive electric energy storage. The systems are recognized as critically useful for the relatively long-term power storage operation, such as efficient storage and supply of the renewable power derived electric energy and grid stabilization.

The IEC 62282-8 series aims to develop performance test methods for power storage and buffering systems based on electrochemical modules (combining electrolysis and fuel cells, in particular reversible cells), taking into consideration both options of re-electrification and substance (and heat) production for sustainable integration of renewable energy sources.

Under the general title Energy storage systems using fuel cell modules in reverse mode, the IEC 62282-8 series consists of the following parts:

- IEC 62282-8-101: Test procedures for the performance of solid oxide single cells and stacks, including reversible operation
- IEC 62282-8-102: Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation
- IEC 62282-8-103[1]: Alkaline single cell and stack performance including reversible operation
- IEC 62282-8-201: Test procedures for the performance of power-to-power systems
- IEC 62282-8-202[2]: Power-to-power systems – Safety
- ~~IEC 62282-8-300 (all parts)[3]: Power -to-*substance* systems~~
- IEC 62282-8-301: Power to methane energy systems based on solid oxide cells including reversible operation – Performance test methods

As a priority dictated by the emerging needs for industry and opportunities for technological development, IEC 62282-8-101, IEC 62282-8-102 and IEC 62282-8-201 were initiated jointly and firstly. These parts are presented as a package to highlight the need for an integrated approach as regards the system's application (i.e. a solution for energy storage) and its fundamental constituent components (i.e. fuel cells operated in reverse or reversing mode).

~~IEC 62282-8-103, IEC 62282-8-202 and IEC 62282-8-300 (all parts) are suggested but are left for initiation at a later stage.~~

1 Future project.

2 Future project.

~~3 Under consideration.~~

FUEL CELL TECHNOLOGIES –

Part 8-201: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of power-to-power systems

1 Scope

This part of IEC 62282 defines the evaluation methods of typical performances for electric energy storage systems using hydrogen. It is applicable to the systems that use electrochemical reaction devices for both power charge and discharge. This document applies to systems that are designed and used for service and operation in stationary locations (indoor and outdoor).

The conceptual configurations of the electric energy storage systems using hydrogen are shown in Figure 1 and Figure 2.

Figure 1 shows the system independently equipped with an electrolyser module and a fuel cell module. Figure 2 shows the system equipped with a reversible cell module.

~~There are an electrolyser, a hydrogen storage and a fuel cell, or a reversible cell, a hydrogen storage and an overall management system (which may include a pressure management) as indispensable components. There may be a battery, an oxygen storage, a heat management system (which may include a heat storage) and a water management system (which may include a water storage) as optional components. The performance measurement is executed in the area surrounded by the outside thick solid line square (system boundary).~~

Indispensable components are an electrolyser module and a fuel cell module, or a reversible cell module, an overall management system (which includes a data interface and can include a pressure management), a thermal management system (which can include a thermal storage), a water management system (which can include a water storage) and a purge gas supply (inert gas, practically neither oxidizing nor reducing).

NOTE 1 Indispensable components are indicated by bold lines in Figure 1 and Figure 2.

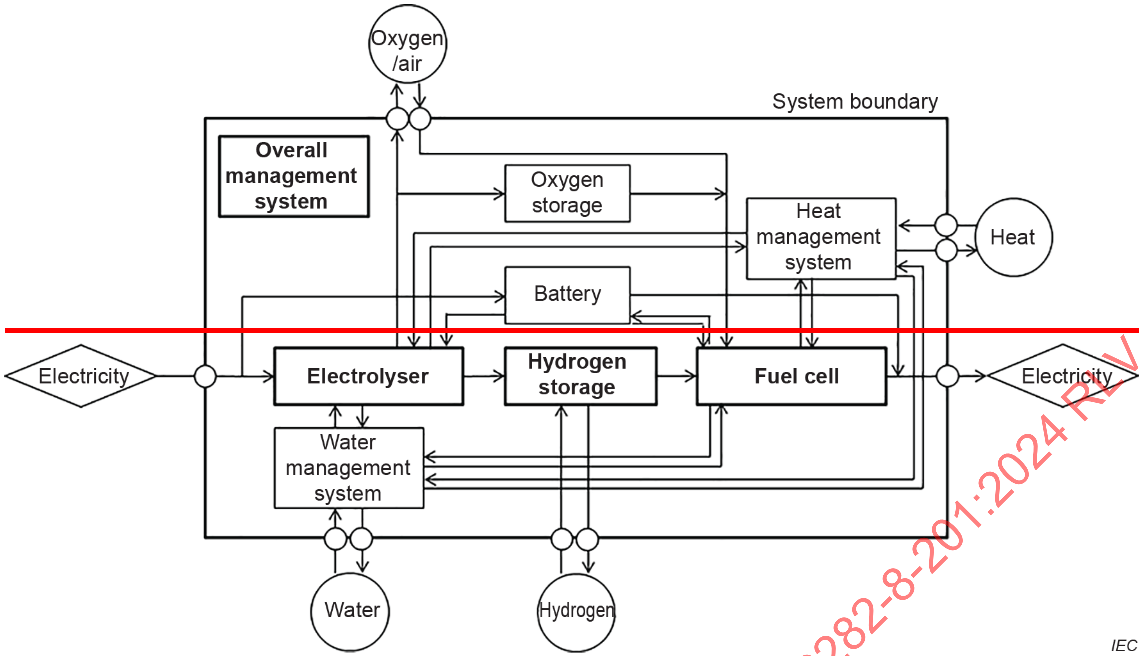
The system can be equipped with either a hydrogen storage or a connection to an external hydrogen supply infrastructure or a combination of both. There can be a battery and an oxygen storage, as optional components.

The electrolyser module can comprise one or more electrolysers whether or not of the same type. Depending on the operating conditions and considering the operation history, the overall management system can command the concurrent operation of the electrolysers. The fuel cell module can comprise one or more fuel cells whether or not of the same type. Depending on the operating conditions and considering the operation history, the overall management system can command concurrent operation of the fuel cells. The reversible cell module can comprise one or more reversible cells whether or not of the same type. The fuel cell module can comprise one or more fuel cells whether or not of the same type. Depending on the operating conditions and considering the operation history, the overall management system can command concurrent operation of the reversible cells.

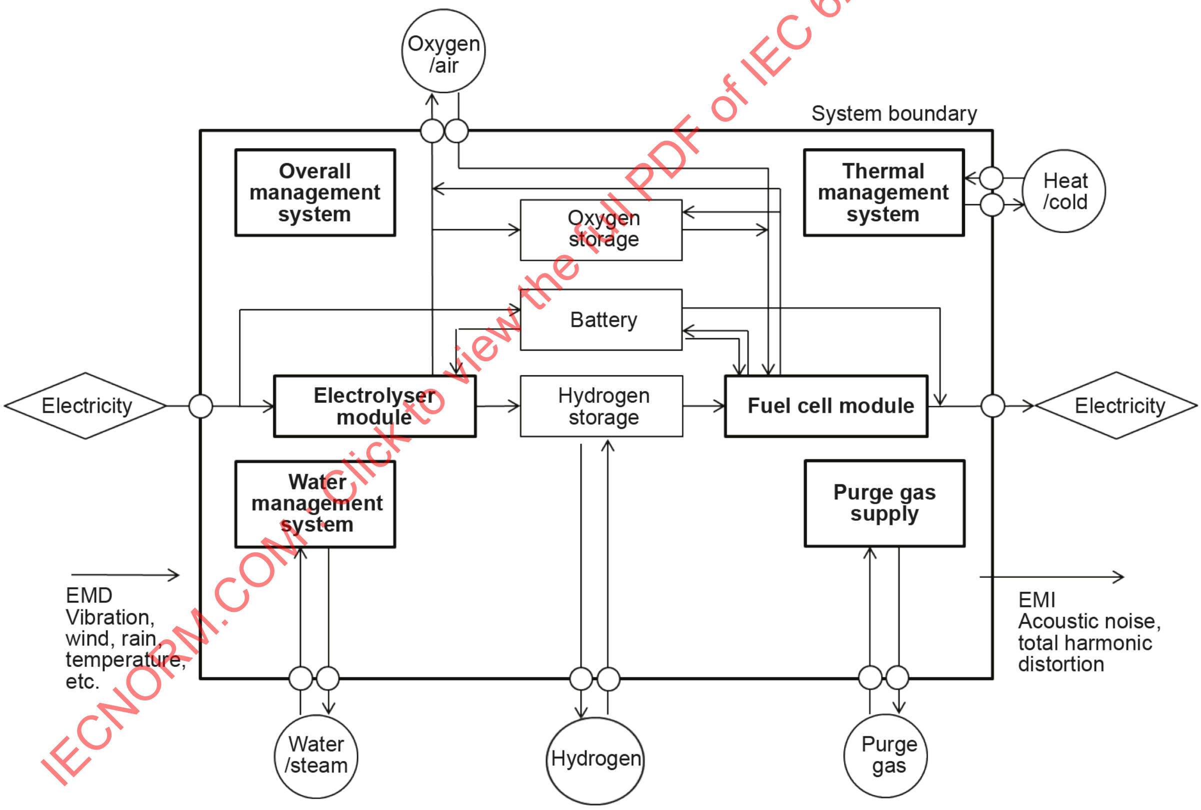
The performance measurement is executed in the defined area surrounded by the bold outside solid line (system boundary).

NOTE 2 In the context of this document, the term "reversible" does not refer to the thermodynamic meaning of an ideal process. It is common practice in the fuel cell community to call the operation mode of a cell that alternates between fuel cell mode and electrolysis mode "reversible".

This document is intended to be used for data exchanges in commercial transactions between the system manufacturer and customer. Users of this document can selectively execute test items suitable for their purposes from thosespecified in this document.



IEC



IEC

Key

EMD electromagnetic disturbance

EMI electromagnetic interference

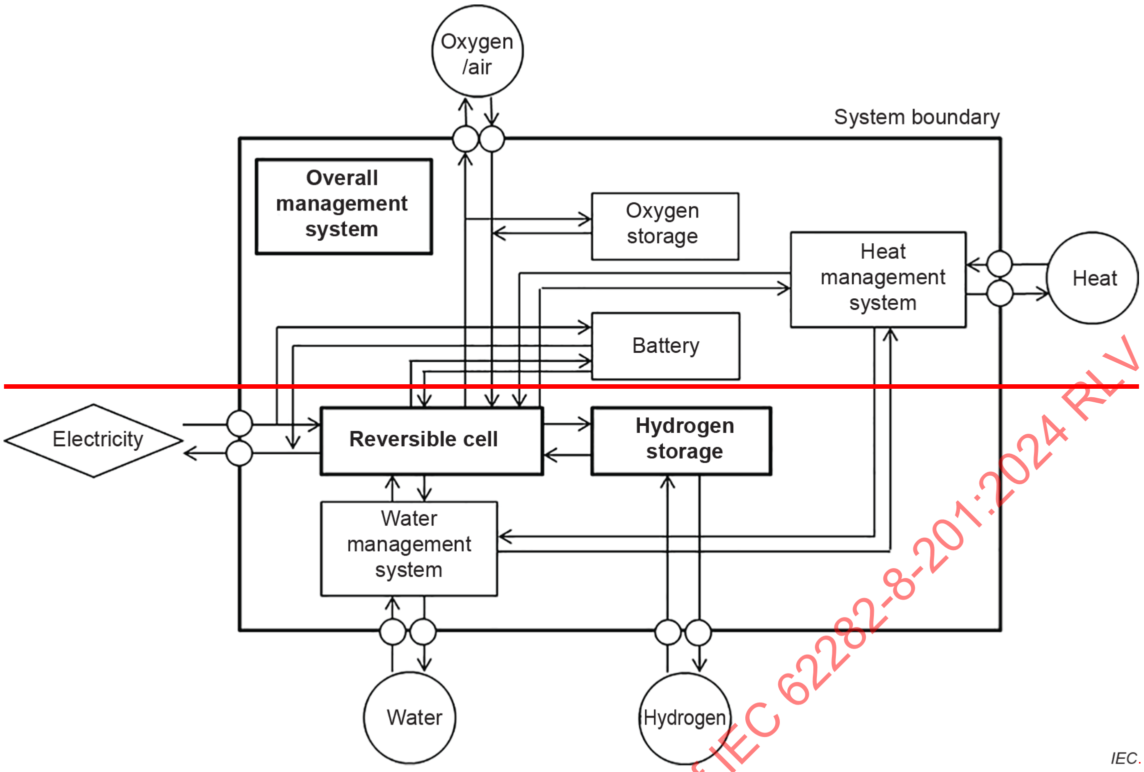
NOTE 1 Overall management system, thermal management system, water management system and purge gas supply can have the relation with electrolyser, fuel cell, battery, hydrogen storage and oxygen storage, and also can have the relation with one another.

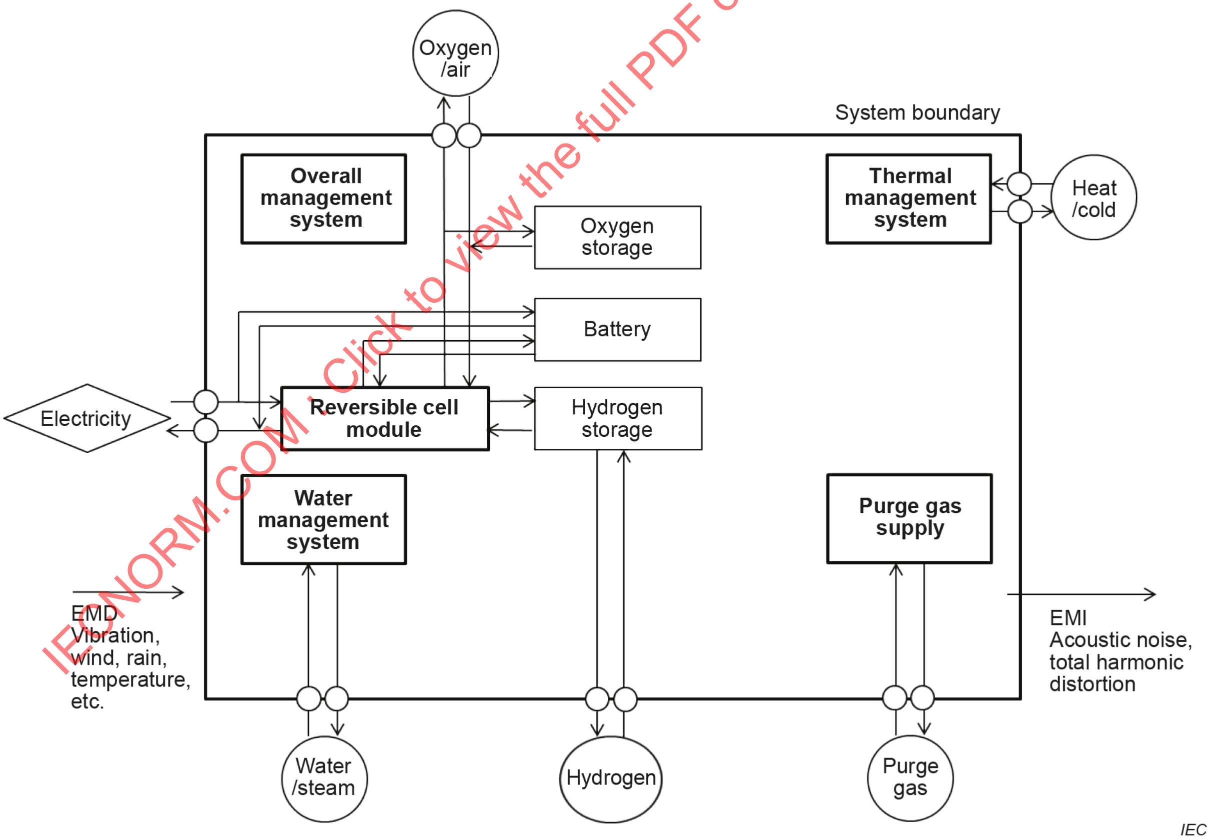
NOTE 2 Other fluid or energy in- or outputs, depending on the used electrolyser and fuel cell types, can be considered.

NOTE 3 The electricity input and output can be DC or AC or both. Power conditioning sub-systems are usually used.

NOTE 4 There can be more than one electricity point of connection for input or output or both.

Figure 1 – System configuration of electric energy storage system using hydrogen – Type with electrolyser and fuel cell





Key

EMD electromagnetic disturbance

EMI electromagnetic interference

NOTE 1 Overall management system, thermal management system, water management system and purge gas supply can have the relation with reversible cell, battery, hydrogen storage and oxygen storage, and also can have the relation with one another.

NOTE 2 Other fluid or energy in- or outputs, depending on the used electrolyser and fuel cell types, can be considered.

NOTE 3 The electricity input and output can be DC or AC or both. Power conditioning sub-systems are usually used.

NOTE 4 There can be more than one electricity point of connection for input or output or both.

Figure 2 – System configuration of electric energy storage system using hydrogen – Type with reversible cell

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

IEC 61427-2, *Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 2: On-grid applications*

IEC 62282-3-200, *Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods*

IEC 62282-3-201, *Fuel cell technologies – Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems*

IEC 62282-8-101, *Fuel cell technologies – Part 8-101: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of solid oxide single cells and ~~stack performance~~ stacks, including reversible operation*

IEC 62282-8-102, *Fuel cell technologies – Part 8-102: Energy storage systems using fuel cell modules in reverse mode – Test procedures for ~~PEM~~ the performance of single cells and ~~stack performance~~ stacks with proton exchange membrane, including reversible operation*

IEC 62933-2-1:2017, *Electrical energy storage (EES) systems – Part 2-1: Unit parameters and testing methods – General specification*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO 3746, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Survey method using an enveloping measurement surface over a reflecting plane*

~~ISO 4064-1, *Water meters for cold potable water and hot water – Part 1: Metrological and technical requirements*~~

~~ISO 4064-2, *Water meters for cold potable water and hot water – Part 2: Test methods*~~

~~ISO 7888, *Water quality – Determination of electrical conductivity*~~

ISO 9614-1, *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 1: Measurement at discrete points*

ISO 11204, *Acoustics – Noise emitted by machinery and equipment – Determination of emission sound pressure levels at a work station and at other specified positions applying accurate environmental corrections*

ISO 16111, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

ISO 19880-1, *Gaseous hydrogen – Fuelling stations – Part 1: General requirements*

ISO 19881, *Gaseous hydrogen – Land vehicle fuel containers*

ISO 19882, *Gaseous hydrogen – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers*

~~ISO 19884, *Gaseous hydrogen – Cylinders and tubes for stationary storage*~~

ISO 22734:2019, *Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications*

~~ISO 22734-1, *Hydrogen generators using water electrolysis process – Part 1: Industrial and commercial applications*~~

~~ISO 22734-2, *Hydrogen generators using water electrolysis process – Part 2: residential applications*~~

3 Terms, definitions and symbols

3.1 Terms and definitions

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

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

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

3.1.1
electric energy storage
EES
installation able to store electric energy or which converts electric energy into another form of energy and vice versa, while storing energy

~~Note 1 to entry: EES can be used also to indicate the activity of an apparatus described in the definition during performing its own functionality.~~

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

~~[SOURCE: IEC 62933-1:2018, 3.1, modified – Definition revised and example and note 2 deleted.]~~

3.1.2
electric energy storage system
EES system
installation with defined electrical boundaries, comprising at least one EES, whose purpose is to extract electric energy from the electric power system, store this energy in some manner and inject electric energy into the electric power system and which includes civil engineering works, energy conversion equipment and related ancillary equipment

Note 1 to entry: The EES system is controlled and coordinated to provide services to the electric power system operators or to the electric power system users.

Note 2 to entry: In some cases, an EES system can require an additional energy source during its discharge, providing more energy to the electric power system than the energy it stores.

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

[SOURCE: IEC 62933-1:2018, 3.2, modified – In the definition, "grid connected" and "internally" have been deleted, and "which extracts" has been replaced by "whose purpose is to~~" added~~ extract". Note 2 to entry has been shortened and Note 3 to entry deleted.]

3.1.3
EES system using hydrogen
EES system comprising at least one EES using hydrogen, whose purpose is to extract electric energy from the electric power system, store this energy as hydrogen and inject electric energy into the electric power system, using hydrogen as a fuel

Note 1 to entry: The conceptual configurations of the EES system using hydrogen are referred to in Clause 1.

3.1.4
battery
EES device for electrochemically storing electricity with electricity charge and discharge functions

Note 1 to entry: Batteries are typically employed for absorbing short-term fluctuating electricity input combined with hydrogen storage of an EES system using hydrogen.

3.1.5
electrolyser
electrochemical device that converts water~~/~~ or steam to hydrogen and oxygen by electrolysis reaction

Note 1 to entry: Electrolysers include alkaline water electrolysis device, polymer electrolyte membrane water electrolysis device, solid oxide electrolysis cell device, and other devices of similar type.

3.1.6
environment
surroundings in which an EES system using hydrogen exists, including air, water, land, natural resources, flora, fauna, humans, and their interrelation

3.1.7
fuel cell
electrochemical device that converts the chemical energy of a fuel and an oxidant to electric energy (DC power), heat and reaction products

Note 1 to entry: The fuel and oxidant are typically stored outside of the fuel cell and transferred into the fuel cell as they are consumed.

[SOURCE: IEC 60050-485:2020, 485-08-01]

3.1.8
~~heat~~ thermal management system
subsystem of the EES system using hydrogen, for controlling the ~~heat~~ thermal storage and thermal fluid flows in the system and its POCs (if applicable)

Note 1 to entry: Typically, heat is utilized among the various items of system equipment. An example of the mutual heat utilization is where the exothermic reaction heat of the fuel cell is conveyed to an electrolysis cell, in particular a solid oxide electrolysis cell for endothermic consumption.

3.1.9
hydrogen storage
component of the EES system using hydrogen, for storing hydrogen that is produced by water~~/~~ or steam electrolysis in or supplied to the system

Note 1 to entry: There are several kinds of hydrogen storage equipment depending on the hydrogen storage principles. They include low~~/~~- and high-pressure gas, liquid, hydrogen-absorbing alloy (hydrogen absorbed in reversible metal hydride), non-metal hydrides and others.

3.1.10
hydrogen supply infrastructure
assembly of hydrogen carrying and storing devices providing connection points to hydrogen appliances, which supply hydrogen to the appliance or absorb hydrogen delivered by the appliance

3.1.11
limit operating conditions
conditions not to be exceeded for operating the EES system normally and safely

Note 1 to entry: They are recommended by the EES system manufacturer considering the system characteristics.

3.1.12
net electric energy output
usable electric energy output from the EES system using hydrogen, which is able to serve for the user's purpose, excluding internal and external electric energy dissipation of the system

Note 1 to entry: The internal and external electric dissipation of the EES system is typically electric energy loss from the equipment operations and connections.

Note 2 to entry: The net electric energy output is the difference between the electric energy outputs and inputs at all POCs.

3.1.13
net electric power
power output of the EES system and available for external use

Note 1 to entry: The net electric power output is the difference between the electric power outputs and inputs at all POCs.

3.1.14
operating conditions
conditions at which the tested system, more specifically each item of equipment of the tested EES system, is operated, ~~as well as~~ and including physical conditions such as range of ambient temperatures, pressure, radiation levels, humidity and atmosphere ~~are included~~

3.1.15
operating state
state at which the tested system, more specifically each item of equipment of the tested EES system, is operated at specified conditions

3.1.16
overall management system
subsystem of the EES system using hydrogen, served for monitoring and controlling the EES system using hydrogen, ~~by fulfilling~~ including all equipment and functions for acquisition, processing, transmission, and display of the necessary process information

Note 1 to entry: The overall management system also includes a subsystem containing an arrangement of hardware, software, and propagation media to allow the transfer of messages from one EES system using hydrogen component~~/~~ or subsystem to another one, including the data interface with external links.

Note 2 to entry: Generally, the control subsystem may be connected to the primary POC (just for data exchange) and it can comprise the communication subsystem and the protection subsystem.

Note 3 to entry: The protection subsystem includes one or more items of protection equipment, one or more instrument transformers, transducers, wiring, one or more tripping circuits, one or more auxiliary supplies. Depending upon the principle or principles of the protection system, it may include one end or all ends of the protected section and, possibly, automatic reclosing equipment.

3.1.17
oxygen storage
~~one~~ component of the EES system using hydrogen, for storing oxygen that is produced by water~~/~~ or steam electrolysis in ~~(~~or supplied to~~)~~ the EES system

Note 1 to entry: Oxygen storage is equipped, if needed.

3.1.18
point of connection
POC
point where an EES system using hydrogen is connected to a supply~~/~~ or extraction exterior to the system

Note 1 to entry: Generally, POCs are electricity, heat, water, hydrogen ~~and~~, oxygen~~/~~ and air connection points. They are shown as open circles on the EES system boundary (thick solid-line square) in Figure 1 and Figure 2.

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

3.1.19
~~quiescent state~~ stand-by state
operating state of the EES system, in which the EES system is partly or fully charged and no intended charging and discharging of the stored energy, except self-discharging, takes place

~~**3.1.19**~~
~~**quiescent state loss rate**~~
~~sum of energy loss rate and energy consumption rate of EES system during the quiescent state~~

3.1.20
rated operating conditions
conditions which are applied for standard operation of equipment ~~and/~~or systems

Note 1 to entry: Rated operating conditions are recommended by the equipment ~~and/~~or EES system manufacturers considering the ~~respective~~ characteristics of the equipment~~/~~ or system.

3.1.21
rated input conditions
conditions specified by the manufacturer, at which the tested EES system absorbs electric power input at the POC

Note 1 to entry: The rated input conditions include the rates of net electric power, heat, water flow, oxygen flow and air flow.

3.1.22
rated output conditions
conditions specified by the manufacturer, at which the tested EES system delivers electric power output at the POC

Note 1 to entry: The rated output conditions include the rates of net electric power, heat, water flow, oxygen flow and air flow.

3.1.23
rated test conditions
specific boundary conditions at which the tested EES system is operated

Note 1 to entry: Rated test conditions are agreed between the EES system manufacturer and customer.

3.1.24
reversible cell
electrochemical device that is able to operate as a fuel cell or as an electrolyser, alternatively

Note 1 to entry: The term "reversible" in this context does not refer to the thermodynamic principle of an ideal process.

3.1.25
roundtrip electrical efficiency
electric energy discharged measured on the primary POC divided by the electric energy absorbed, measured on all the POCs (primary and auxiliary), over one EES system standard charging–discharging cycle under specified operating conditions

~~Note 1 to entry: Efficiency is generally expressed in percentage.~~

Note 1 to entry: The auxiliary POC is used for electricity supply of auxiliary components and devices such as instrumentation, controls, monitoring and safety functions.

3.1.26
operation history
record of the operating conditions of the system

3.1.27
steady state
state of an EES system in which the relevant characteristics remain constant with time

[SOURCE: IEC 60050-485:2020, 485-21-05, modified – In the definition, “physical” has been replaced with “EES”.]

3.1.28
switchover time
time that is required to switch an EES system using hydrogen from a specified charging phase to a specified discharging phase or vice versa

Note 1 to entry: This can be of relevance in case grid service ~~shall~~ is required to be performed with the EES system. It comprises the time that is required to go from one operating point in either charging or discharging operation to ~~quiescent~~ stand-by state, purging of gas lines if applicable, setting of auxiliary components (valves, heaters, compressors, etc.) if applicable and to go to an operating point in the opposite operating phase (discharging or charging).

3.1.29
test state
state of the tested EES system that is consistent with the objective of the evaluation

~~Note 1 to entry: More specifically, it means the specific operating state for equipment of the tested system.~~

3.1.30
tested system
EES system defined by its boundary to the environment that is in accordance with the objective of the evaluation

3.1.31
water management system
subsystem of the EES system using hydrogen, for controlling the water flow, the steam flow or both in the EES system

Note 1 to entry: Water management system includes the controlling mechanisms of water inlet, transport, purifying (if applicable), and drain.

3.2 Symbols

~~The symbols and their meanings used in this document are given in Table 1, with the appropriate units.~~

Table 1 lists the symbols and units that are used in this document.

Table 1 – Symbols

Symbol	Definition	Unit	Formula	Figure
k	Coverage factor			
$m_{\mathrm{H2,in}}$	Hydrogen mass supplied to the system at the POC	g	(4)	
n	Number of measurements until discharge completion		(3), (4)	
P_{el}	~~Active~~ Electric power at the POC	W	(2)	
$P_{\mathrm{el,loss}}$	~~Quiescent~~ Stand-by state loss rate	W	(6)	
$P_{\mathrm{el,in}}$	Net electric power input	W		
$P_{\mathrm{el,out}}$	Net electric power output	W	(3)	
$\mathrm{d}P/\mathrm{d}t$	Ramp rate	W/s	(2)	Figure 5
$P_{\mathrm{th,in}}$	Heat input	W		
$P_{\mathrm{th,out}}$	Heat output	W		
$q_{m,\mathrm{H2,in}}$	Hydrogen mass flow into the system at the POC	g/s	(4)	
$q_{m,\mathrm{H2,out}}$	Hydrogen mass flow out of the system at the POC	g/s		
t_0	Time when the system, which is ~~at rest~~ in steady state, receives the set point value	s	(1)	Figure 4
t_1	Time when the ~~active~~ electric power at the POC becomes less than 90 % for negative state or higher than 10 % for positive state of the set point value	s	(2)	Figure 4
t_2	Time when the ~~active~~ electric power at the POC becomes less than 10 % for negative state or higher than 90 % for positive state of the set point value	s	(2)	Figure 4
t_3	Time when the ~~active~~ electric power at the POC reaches within 2 % of the set point value	s	(1)	Figure 4
t_{loss}	Measurement time of self-discharging	h	(6)	
t_{so}	Switchover time	s		Figure 6
t_{sr}	Step response time	s	(1)	Figure 5
W_{el}	Electric energy storage capacity	Wh	(3)	
$W_{\mathrm{el,in}}$	Electric energy input	Wh	(5), (6)	
$W_{\mathrm{el,out}}$	Net electric energy output	Wh	(3)	
Δt	Sampling time of measurement	h, s	(3)	
η_{el}	Roundtrip electrical efficiency	%	(5)	

4 Measurement instruments and measurement methods

4.1 General

For measuring certain properties of the tested EES system, the configuration of its components and the boundary conditions to the environment shall be determined first.

Attention is required to clearly define the tested EES system. The components which the tested EES system includes and the conditions of the test environment at all points of connection (POC) shall be defined. The POCs are input~~/~~ and output ~~of~~ connections for electricity, heat, water, hydrogen, oxygen and air. The boundary conditions for all POCs shall be defined.

Secondly, the test state of the EES system shall be defined. The test state of the EES system means the operating levels compared to the maximum capability of either the EES system or one of its components at the time of test execution.

Then the operating conditions for the test shall be defined. They shall be agreed between the ESS system manufacturer and the customer.

~~It shall be noted that the operation history and the actual operating time of the system affects the evaluation of system performance values.~~ During execution of the tests, the operating times shall be noted. They are the electric input time, the electric output time, the input-and-output ~~quiescent~~ stand-by period, and combination patterns thereof. The operation history and the actual operating time of the system affects the evaluation of the EES system performance, therefore the history of the operating times of the EES system before executing the test shall also be reported.

Where it is unfeasible to perform measurements of electric power or media flow at full scale due to large system size, for safety related reasons or lack of suitable instrumentation, measurements may be performed at sub-system level. Such measurements shall allow derivation of data representative of measurements at full system size. The measurement concept applied shall be detailed in the test report (see 7.4).

4.2 Instrument uncertainty

The expanded uncertainty of each measuring instrument (coverage factor k = 2) at the time of calibration or that estimated from the class of instrument shall meet the following requirements:

- electric power: ±2 % of reading;
- current: ±1 % of reading;
- voltage: ±1 % of reading;
- mass flow: ±1 % of reading;
- ambient temperature: ±1 K;
- ambient pressure: ±0,1 kPa;
- ambient relative humidity: ~~±1 % (absolute)~~ ±5 %.

Instruments that satisfy the above requirements shall be used. ISO/IEC Guide 98-3 shall apply.

4.3 Measurement plan

The components' configuration, the boundary conditions to the environment of the tested EES system and the test state shall be clearly defined. The test state shall be considered according to the application and usage. Also, the test phases, which are charge, storage and discharge illustrated in Figure 3, should be considered.

The rated and the limit operating conditions for the tested EES system are confirmed between the system manufacturer and the customer. The rated and the limit operating conditions for each component shall be established from the component manufacturers' specifications.

Then the sequence of the measurements shall be planned. It shall be considered that certain properties of some components relate to the conditions ~~and/~~or the ~~condition~~ settings for other components. For example, the operating state of the hydrogen storage capacity relates to the operating conditions settings of the electrolyser. Also, attention should be paid to the fact that some properties can change considerably during the measurement. For example, the electric power input can vary during a charging phase. The test state shall be clearly defined and the property changes during the measurement shall be identified. For setting up the measurement methods and instruments, instrument uncertainty and permissible variation shall be checked and reported. ~~The related regulations shall be considered.~~ The ~~required steps~~ actions to be made before executing the measurement are summarized in Table 2.

After confirming that the EES system is operating under the test state, the measurement for testing the EES system performance is executed.

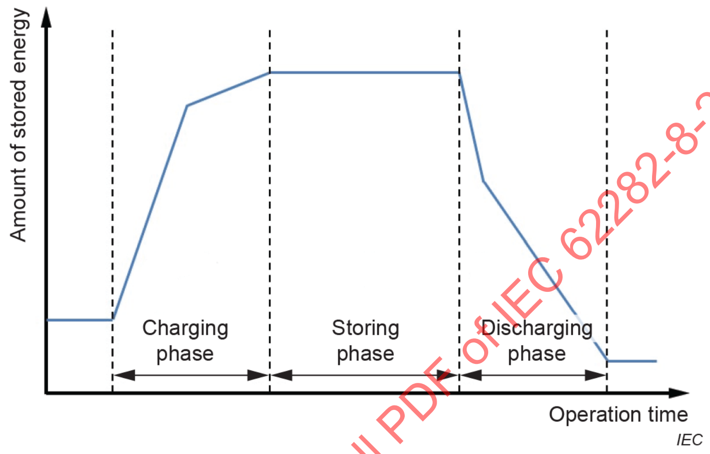


Figure 3 – Typical sequence of phases during the system operation

Table 2 – Required steps before executing the measurement

~~Requirements~~ Required steps		~~Remarks~~ Actions
1	Note the system components' configuration.	
2	Define the system boundary.	Define ambient conditions ~~shall be defined~~.
3	Note the initial operating state of the system.	Report the operation history of the system ~~shall be reported~~.
4	Confirm the rated operating conditions and the limit operating conditions for the system.	Confirm the rated operating conditions and the limit operating conditions for the system ~~shall be confirmed~~ between system manufacturer and customer.
5	Define the tests to be executed.	Consider the mutual interaction of the system components ~~shall be considered~~.
6	Define the measurement methods and set up the instruments.	Check and report instrument uncertainty and permissible variation ~~shall be checked and reported~~. Execute safety measures ~~shall be taken~~.
7	Execute the measurement.	

4.4 Environmental conditions

The reference environmental conditions shall be the normal environmental conditions as specified in IEC 62933-2-1.

Air temperature, relative humidity and pressure shall be measured as ambient conditions. Supplementary items shall be recorded, if needed. In the case of an outdoor installation, the information concerning hoarfrost, dew, hail, rain, snow, wind, and solar radiation shall be recorded.

When the EES system is intended to be used under conditions different from the reference environmental conditions, an agreement shall be established between the system manufacturer and the customer ~~is necessary~~. In those cases, the appropriate ambient conditions for the test shall be ~~considered~~ agreed between the system manufacturer and the customer.

If required, the EES system may also be tested under the most extreme environmental conditions. In this case, the EES system manufacturer shall provide the most extreme environmental conditions.

4.5 Maximum permissible variation in test operating conditions

The tolerable variation of each operating parameter in the testing EES system shall fall within the following range:

– power: ±5 % relative to set point;
– ambient temperature: ±5 K;
– ambient relative humidity: ±10 %.

5 System parameters

5.1 General

The following parameters shall be specified as the common basic parameters to ensure capability and performance of an EES system using hydrogen:

- electric energy storage capacity;
- rated electric power input;
- rated net electric power output;
- roundtrip electrical efficiency.

In addition, the following parameters shall be specified if required:

- system response (step response time and ramp rate);
- minimum switchover time;
- ~~quiescent~~ stand-by state loss rate;
- thermal ~~power~~ input and output;
- hydrogen input and output;
- acoustic noise level;
- total harmonic distortion;
- discharge water quality;
- electrolyser performance;
- hydrogen storage performance;
- fuel cell performance;
- water management system performance;
- battery performance;
- oxygen storage performance.

5.2 Electric energy storage capacity

Electric energy storage capacity is the electric energy that can be extracted from the EES system at the POC under reference environmental conditions as specified in 4.4. The electric energy storage capacity shall be evaluated considering energy losses. The electric energy storage capacity is the electric energy discharged from fully charged state to fully discharged state of the EES system, at rated output conditions. ~~The rated output conditions include input and output rates of net electric power, heat, water flow and oxygen/air flow. They shall be agreed by the system manufacturer and the customer.~~

The EES system may contain several types of energy source storages other than electricity and hydrogen, such as heat and oxygen. In those cases, each property of the components related to the energy source storages ~~is recommended to~~ should be reported separately, adding to the electric energy storage capacity for the EES system.

5.3 Rated electric power input

The rated electric power input ($P_{\mathrm{el,in}}$) is the ~~value of~~ electric power that the tested EES system can absorb for a specified time at the POC under the reference environmental conditions specified in 4.4. The rated electric power input shall be specified together with applicable input duration. The rated electric power input and the applicable input duration, along with the conditions including input and output rates of heat, water flow ~~and~~, oxygen~~/~~ flow and air flow, shall be agreed by the system manufacturer and the customer.

In the case where more than one POC for electric power input is present in the EES system, rated electric power input is calculated from the total of the concurrent measurements of all electric power inputs at the POC. Typically, it contains the electric power inputs of the electrolyser or reversible cell, battery and other electrically operated components.

5.4 Rated net electric power output

The rated net electric power output ($P_{\mathrm{el,out}}$) is the ~~value of~~ net electric power that the tested EES system can provide for a specified time at the POC under the reference environmental conditions specified in 4.4. The rated net electric power output shall be specified together with applicable output duration. The rated net electric power output and the applicable output duration, along with the conditions including input and output rates of heat, water flow ~~and~~, oxygen~~/~~ flow and air flow, shall be agreed by the system manufacturer and the customer.

In the case where more than one electric POC is present in the EES system, rated net electric power output is calculated from the difference of the measured electric power outputs and inputs at all POCs. Typically, it contains the electric power connections of the fuel cell or the reversible cell and the battery.

5.5 Roundtrip electrical efficiency

The roundtrip electrical efficiency (η_{el}) is the ratio of net electric energy output ($W_{\mathrm{el,out}}$) during discharging to electric energy input ($W_{\mathrm{el,in}}$) during charging of the EES system for one charging–discharging cycle which has the same energy storage level at the start and at the end of the measurement.

NOTE Since the net electric energy output is considered during discharging, the electric energy input during this phase does not have to be added to the electric energy input during charging.

The boundary conditions of an electric input and output are defined. The test state is defined. The operating conditions for testing are determined. They include input and output rates of net electric power, heat, water flow ~~and~~, oxygen~~/~~ flow and air flow, and energy storage levels of electric energy and energy other than electricity. They shall be agreed by the system manufacturer and the customer. These items shall be reported with the measurement results.

The roundtrip electrical efficiency is measured over one charging–discharging cycle for specified energy storage levels using specified input and output rates of net electric power, heat, water flow ~~and~~, oxygen~~/~~ flow and air flow. At the end of the charging–discharging cycle, the level of charge and the operating conditions of the tested EES system shall be the same as those before the charging–discharging cycle.

For EES systems with an internal hydrogen storage, the charging–discharging cycle is defined by operation from the minimum to the maximum state of charge of the hydrogen storage and back to minimum state of charge. For EES systems without an internal hydrogen storage, the charging–discharging cycle is defined by comparing the mass of hydrogen which is delivered during charging operation and the mass of hydrogen which is supplied during discharging operation. The cycle is complete when the mass of the delivered hydrogen during charging equals the mass of the supplied hydrogen during discharging.

The roundtrip electrical efficiency can be affected by energy storage levels, electric power input and net output rates, electric energy consumption of the system operation, operating conditions for components relating to an energy source other than electricity, as well as the reference environmental conditions.

5.6 System response (step response time and ramp rate)

5.6.1 Step response time

The step response time of the EES system is the duration of the time interval between the instant t_0 when the EES system, which is ~~at rest~~ in steady state, receives the set point and the instant t_3 when the ~~active~~ electric power at the POC reaches the set point (within ±2 %) as shown in Figure 4. Detailed definition of t_0 shall be agreed between the system manufacturer and the customer. The reference set point for the definition of the step response time is the rated input~~/~~ or output power.

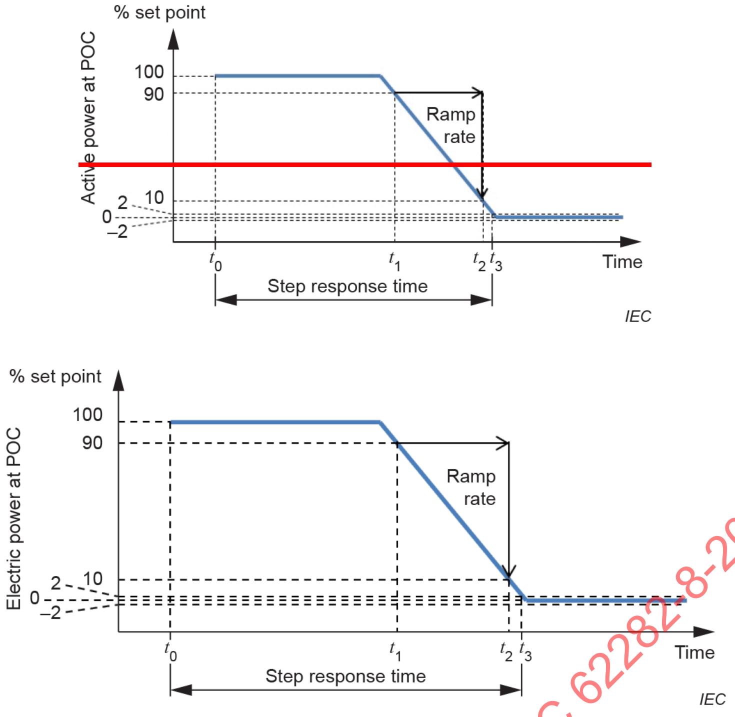
$$t_{sr} = t_3 - t_0 \tag{1}$$

where

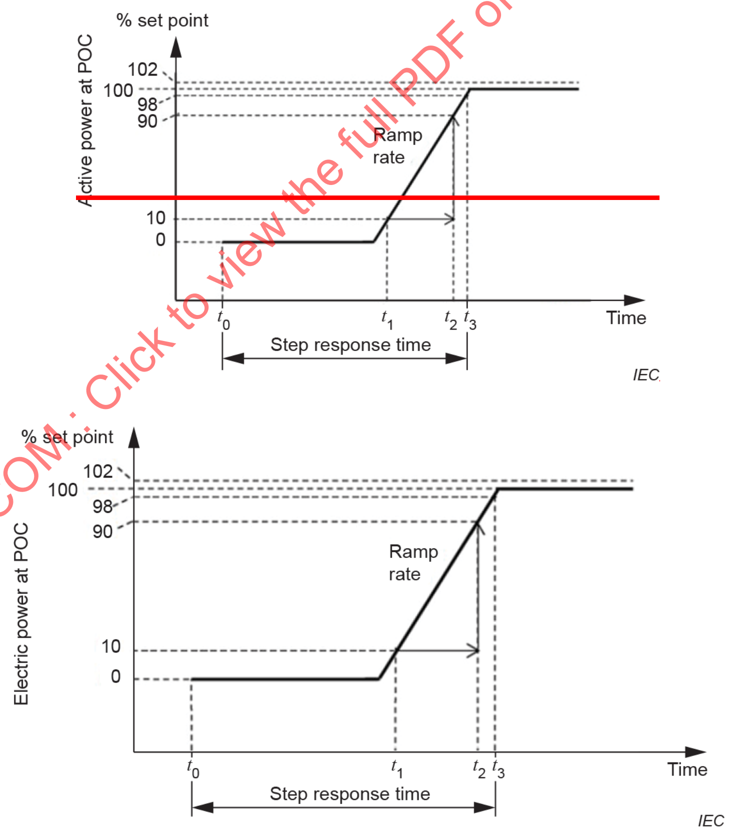
t_{sr} is the step response time (s);

t_0 is the time point when the EES system, which is ~~at rest~~ in steady state, receives the set point value;

t_3 is the time point when the ~~active~~ electric power at the POC reaches the set point (within ±2 %).



a) Negative ramp rate



b) Positive ramp rate

~~NOTE The figure is taken from IEC 62933-2-1:2017, Figure 5 and has been modified.~~

NOTE The ramp rate and the parameters t_1 and t_2 are explained in 5.6.2.

Figure 4 – Step response time and ramp rate of EES system

5.6.2 Ramp rate

The ramp rate of the EES system is the average rate of ~~active~~ electric power variation per unit of time between t_2 and t_1 as shown in Figure 4 a) for negative ramp rate and Figure 4 b) for positive ramp rate. For the negative (positive) state, t_1 is the time point when the ~~active~~ electric power at the POC becomes less than 90 % (higher than 10 %) of the set point value and t_2 is the time point when the ~~active~~ electric power at the POC becomes less than 10 % (higher than 90 %) of the set point value. The reference set point for the definition of the ramp rate is the rated input and output power. In case of non-linear characteristic or transition behaviour during the mode change, for example charge–discharge–charge, the definition of ramp rate shall be agreed by the system manufacturer and the customer.

$$\mathrm{d}P / \mathrm{d}t = \frac{P_{\mathrm{el}}(t_2) - P_{\mathrm{el}}(t_1)}{t_2 - t_1} \tag{2}$$

where

$\mathrm{d}P/\mathrm{d}t$	is the ramp rate (W/s);
t_1	is the time point when the ~~active~~ electric power at the POC becomes less than 90 % (negative ramp rate) or higher than 10 % (positive ramp rate) of the set point value;
t_2	is the time point when the ~~active~~ electric power at the POC becomes less than 10 % (negative ramp rate) or higher than 90 % (positive ramp rate) of the set point value;
$P_{\mathrm{el}}(t_1)$	is the ~~active~~ electric power at the POC at time point t_1;
$P_{\mathrm{el}}(t_2)$	is the ~~active~~ electric power at the POC at time point t_2.

5.7 Minimum switchover time

The minimum switchover time is the minimum duration required to switch the operating conditions of the tested EES system from a specified charging phase to a specified discharging phase, or vice versa. It specifically comprises the time that is required to go from a specified charging or discharging phase to open circuit voltage (OCV) phase, purging of gas lines if applicable, setting of auxiliary components if applicable and to go to the opposite specified operating phase. The switchover times from charging to discharging phase and vice versa can be different, so both values shall be reported. The charging and discharging phases for the test (for example, 80 % of the nominal input and output power rates) shall be agreed between the system manufacturer and the customer.

5.8 ~~Quiescent~~ Stand-by state loss rate

The ~~quiescent~~stand-by state loss rate of the EES system is the sum of the energy loss rate and the energy consumption rate of the EES system during the ~~quiescent~~ stand-by state, which is typically the phase between the charge and the discharge operation. The measurement time of the ~~quiescent~~ stand-by state loss rate shall be chosen from among one hour, one day or one week or the time agreed upon by the system manufacturer and the customer. The energy consumption of any auxiliary operation within the system boundary shall be included.

NOTE Stand-by state energy losses include electric energy losses such as parasitic loads or supply of controls and gas losses.

5.9 Heat input ~~rate~~

The heat input ~~rate~~ ($P_{\mathrm{th,in}}$) is the thermal power, which is absorbed by the tested EES system during the system operation in the different operation phases (charging, storage, discharging). The heat input is fed to the EES system at the POC, using a heat transfer fluid (e.g. air, water, steam).

In the case where there is more than one POC for heat input, the heat input ~~rate~~ is calculated from the total of concurrent measurements of all heat ~~input rates~~ inputs at the POC.

5.10 Hydrogen input and output rate

For systems connected to a hydrogen supply infrastructure, the hydrogen input rate ($q_{m,\mathrm{H2,in}}$) and hydrogen output rate ($q_{m,\mathrm{H2,out}}$) are the mass flow rate of hydrogen at the POC into and out of the tested EES system, respectively, during the different operation phases (charging, storage, discharging).

5.11 Recovered heat output ~~rate~~

The recovered heat output ~~rate~~ ($P_{\mathrm{th,out}}$) is the usable thermal power output, which is recovered by the tested EES system during the system operation in the different operation phases (charging, storage, discharging). The recovered heat output is dissipated at the POC, using a heat transfer fluid (typically water). The recovered heat output ~~rate~~ does not include waste heat losses, for example due to system components cooling.

5.12 Acoustic noise level

The acoustic noise level is the total acoustic noise level, including all noise sources of the EES system. It shall be measured under the rated operating states ~~and/~~or those states which are agreed between the system manufacturer and the customer.

5.13 Total harmonic distortion

The total harmonic distortion is the overall harmonic distortion of the EES system. It shall be measured under the rated operating states ~~and/~~or those states which are agreed between the system manufacturer and the customer.

5.14 Discharge water quality

All discharge water sources of the EES system are covered. The quality of the discharged water shall be measured under the rated operating states ~~and/~~or those states which are agreed between the system manufacturer and the customer.

6 Test methods and procedures

6.1 General

System parameters specified in Clause 5 and component performances shall be reported selectively according to the purpose of the performance test.

The parameters listed in 5.2 to 5.5 are primary performance indicators of the EES system using hydrogen. They are measured under the rated test conditions or other operating conditions within the limit operating conditions. These conditions for testing shall be agreed between the system manufacturer and the customer.

The other parameters listed in Clause 5 are secondary performance indicators of the EES system. The testing conditions as specified in 4.4 shall be applied, based upon agreement between the system manufacturer and the customer.

Suitable performance test standards for electricity-converting devices and EES shall be followed as available.

6.2 Electric energy storage capacity test

Electric energy storage capacity shall be tested at rated input and output conditions under reference environmental conditions as specified in 4.4, and if required, at additional operating conditions different from the rated ones.

For EES systems with an internal hydrogen storage, which are connected to an external hydrogen supply, the hydrogen supply at the POC shall be closed during this test. The electric energy storage capacity can not be determined for EES systems without an internal hydrogen storage. Only in case of a limited and known state of charge of the external hydrogen supply infrastructure can the latter be considered like an internal hydrogen storage and the electric energy storage capacity be determined.

The electric energy storage capacity shall be evaluated as the electric energy discharged at the rated output conditions and the output duration time starting from the fully charged state of the system. Values of output power from the tested EES system shall be obtained at all POCs using a calibrated power meter or a calibrated combination of one or more voltmeters and amperemeters, as appropriate.

For the measurement of the electric power input, the test methods of ISO 22734:2019 for electrolysers, IEC 62282-3-200 for stationary fuel cells, IEC 62282-8-101 for reversible solid oxide electrolysis (SOE) cells and IEC 62282-8-102 for reversible polymer electrolyte membrane (PEM) cells shall apply. Furthermore, the guidelines of IEEE Std 1459™-2010 may be used.

The measurement shall be performed in the three consecutive steps a) to c). The electric energy storage capacity shall be calculated by Formula (3).

a) The tested EES system shall be discharged to the specified minimum electric energy storage level in accordance with the system specifications and operating instructions.

b) The tested EES system shall be charged to the specified maximum electric energy storage level at rated input conditions in accordance with the system specifications and operating instructions.

c) The tested EES system shall be discharged at the rated output conditions of the system in accordance with the system specifications and operating instructions. The EES system shall be discharged to the specified minimum electric energy storage level associated with the system specification and operation instructions. The net electric power output over time shall be measured and recorded.

Subsequently, the net electric energy output is calculated using Formula (3). The electric energy storage capacity (W_{el}) is defined as the net electric energy output during this test ($W_{\text{el,out}}$).

$$\cancel{W_{\text{el}} = W_{\text{el,out}} = \sum_{i=1}^{n} P_{\text{el,out}}\left(t_i\right) \times \Delta t}$$

$$W_{\text{el}} = W_{\text{el,out}} = \sum\nolimits_{i=1}^{n} P_{\text{el,out}}\left(t_i\right) \times \Delta t \qquad (3)$$

where:

W_{el} is the electric energy storage capacity of the tested EES system (Wh);

$W_{\text{el,out}}$ is the calculated net electric energy output ~~at the POC~~ (Wh);

$P_{\mathrm{el,out}}(t_i)$ is the net electric power output at time point t_i, ~~measured at the POC~~ (W);

Δt is the sampling time of measurement (h);

n is the number of measurements until discharge completion.

The rated input and output operation conditions shall also be reported. If the energy storage capacities of components of the EES are reported separately, the following standards shall apply:

- hydrogen storage capacity of hydrogen tanks: performance test methods of the related parts in ISO 16111, ISO 19880-1, ISO 19881 and ISO 19882~~ and ISO 19884~~;
- electricity storage capacity of batteries and similar components: performance test methods of IEC 61427-1 and IEC 61427-2.

For components without suitable test standards for the evaluation of energy storage capacities, the applied test method and conditions shall be reported.

6.3 Rated electric power input test

The rated electric power input test of the EES system shall be conducted to confirm that constant rated electric power can be input to the system for a specified duration at the POC. This test shall be performed using the electric energy storage capacity measurement test routine in 6.2 as follows.

It shall be confirmed that the tested EES system can absorb, or be charged at, the set electric power for a specified duration at the POC. The rated electric power input of the system shall be applied as the set electric power value in this test.

In step b) of the electric energy storage capacity test in 6.2, the rated electric power is input to the tested EES system at the set electric power. The input electric power and the charging time shall be measured. The measured values of the input electric power and the charging time duration shall be compared to the specified parameters and reported. The duration for which this rated electric power is maintained shall be measured and reported. The rated input operating conditions shall also be reported.

~~For the measurement of the electric power input, the test methods of ISO 22734-1, ISO 22734-2 for electrolysers, IEC 62282-3-200 for fuel cells, IEC 62282-8-101 and IEC 62282-8-102 for reversible cells shall apply.~~

For EES systems without an internal hydrogen storage, which are connected to a hydrogen supply infrastructure, the rated electric power input shall be determined by using step b) of 6.5.2.2 accordingly.

Where an EES system comprises more than one electrolyser, this test may also be conducted at a fraction of the rated electric power which corresponds to the non-concurrent operation of the electrolysers. This fraction may also correspond to the concurrent operation of more than one but not all electrolysers. The same applies to an EES system, which comprises more than one reversible cell. The specified duration at which the selected fraction of rated electric power can be input to the EES system at the POC shall be reduced proportionally. Alternatively, this duration shall be increased so that its value multiplied by the fraction of the rated electric power equals the product of the rated electric power and the original duration (rated electric energy input).

6.4 Rated net electric power output test

The rated net electric power output test of the EES system shall be conducted to confirm that constant rated net electric power can be output from the system for a specified duration at the POC. This test shall be performed using the electric energy storage capacity measurement test routine in 6.2 as follows.

It shall be confirmed that the tested EES system is able to output the set net electric power for a specified duration at the POC. The rated net electric power output of the system shall be applied as the set power value in this test.

In step c) of the electric energy storage capacity test in 6.2, the rated net electric power is output from the tested EES system at the set electric power. The net electric power output and the discharge time shall be measured and reported. The measured values of the net electric power output and the discharge time duration shall be compared to the specified parameters. The duration for which this rated electric power is maintained shall be measured and reported. The rated output conditions shall also be reported.

For EES systems without an internal hydrogen storage, which are connected to a hydrogen supply infrastructure, the rated electric power input shall be determined by using step a) of 6.5.2.2 accordingly.

Where an EES system comprises more than one fuel cell, this test may also be conducted at a fraction of the rated net electric power which corresponds to the non-concurrent operation of the fuel cells. This fraction may also correspond to the concurrent operation of more than one but not all fuel cells. The same applies to an EES system, which comprises more than one reversible cell. The specified duration at which the selected fraction of rated net electric power can be output from the EES system at the POC shall be reduced proportionally. Alternatively, this duration shall be increased so that its value multiplied by the fraction of the rated net electric power equals the product of the rated net electric power and the original duration (rated net electric energy output).

6.5 Roundtrip electrical efficiency test

6.5.1 General

The roundtrip electrical efficiency test shall be conducted to determine the amount of net electric energy output which the tested EES system can deliver, relative to the amount of electric energy input into the system during the preceding charge ~~and discharge~~, under ~~determined~~ specified operating conditions and at the same reference environmental conditions. This test shall be performed using the electric energy capacity test routine presented in 6.2. The test shall be carried out at least twice ~~for one set of measurements at specific operating conditions~~.

6.5.2 Test procedure

6.5.2.1 For systems with internal hydrogen storage, not connected to an external hydrogen supply infrastructure

The net electric energy output $W_{\mathrm{el,out}}$ shall be measured and calculated during the electric energy storage capacity test; see 6.2 c). The electric energy input $W_{\mathrm{el,in}}$ shall be measured and calculated accordingly during the electric energy storage capacity test; see 6.2 b). The electric energy input shall be determined analogously to the net electric energy output, using Formula (3).

6.5.2.2 For systems without internal hydrogen storage, connected to an external hydrogen supply infrastructure

The net electric energy output $W_{\mathrm{el,out}}$ and the electric energy input $W_{\mathrm{el,in}}$ of the tested EES system and the hydrogen mass flow into and out of the tested EES system shall be measured at rated input and output conditions under reference environmental conditions as specified in 4.4 and, if required, at additional operating conditions different from the rated ones.

The values of the input and output power shall be obtained at the electricity POC, using a calibrated power meter or a calibrated combination of one or more voltmeters and amperemeters, as appropriate. The values of the hydrogen mass flow into and out of the tested

EES system shall be obtained at the hydrogen POC, using a calibrated hydrogen mass flow meter.

For the measurement of the electric power input, the test methods of ISO 22734:2019 for electrolysers, IEC 62282-3-200 for stationary fuel cells, IEC 62282-8-101 for reversible solid oxide electrolysis (SOE) cells and IEC 62282-8-102 for reversible polymer electrolyte membrane (PEM) cells shall apply. Furthermore, the guidelines of IEEE Std 1459-2010 may be used.

The measurement shall be performed in the two consecutive steps a) and b).

a) The tested EES system shall be operated in discharging mode at rated output conditions (positive electric power output and hydrogen input) in accordance with the system specifications and operating instructions, for a specified duration.

b) The tested EES system shall be operated in charging mode at rated input conditions (positive electric power input and hydrogen output) in accordance with the system specifications and operating instructions, until the mass of delivered hydrogen equals the mass of hydrogen supplied to the system during step a).

The mass of hydrogen supplied to the system during step a) can be determined using Formula (4). The mass of hydrogen delivered by the system during step b) can be determined accordingly.

$$m_{\mathrm{H2,in}} = \sum_{i=1}^{n} q_{m,\mathrm{H2,in}}\left(t_i\right) \times \Delta t \qquad (4)$$

where

$m_{\mathrm{H2,in}}$ is the hydrogen mass supplied to the system at the POC (g);

$q_{m,\mathrm{H2,in}}$ is the hydrogen mass flow into the system at the POC (g/s);

Δt is the sampling time of measurement (s);

n is the number of measurements until end of discharging operation.

~~The net electric energy output $W_{\mathrm{el,out}}$ shall be measured and calculated during the electric energy storage capacity test (see 6.2 c)). The electric energy input $W_{\mathrm{el,in}}$ shall be measured and calculated accordingly during the electric energy storage capacity test (see 6.2 b)). The electric energy input shall be determined analogue to the net electric energy output, using Equation (3).~~

The net electric energy output $W_{\mathrm{el,out}}$ shall be measured and calculated during step a) and the electric energy input $W_{\mathrm{el,in}}$ shall be measured and calculated during step b). The values shall be determined in the same way as the method in 6.2, using Formula (3).

6.5.3 Calculation of the roundtrip electrical efficiency

The roundtrip electrical efficiency shall be calculated according to Formula (5).

$$\eta_{\mathrm{el}} = \frac{W_{\mathrm{el,out}}}{W_{\mathrm{el,in}}} \times 100\ \% \qquad (5)$$

where

η_{el} is the roundtrip electrical efficiency (%);

$W_{el,out}$ is the net electric energy output ~~measured at the POC, which is considered as electric energy losses including the conversion loss and the electric energy used for the system operation~~ (Wh);

$W_{el,in}$ is the electric energy input ~~measured at the POC~~ (Wh).

NOTE $W_{el,out}$ considers electric energy losses due to energy conversion and the use of electric energy for system operation.

The roundtrip electrical efficiency shall be reported as indicated in Table 3, for example. Where an additional test is performed beyond the minimum required two cycles, an additional row shall be added to Table 3. The average value shall be calculated from each measured value and the roundtrip electrical efficiency shall be reported based on the average value.

Table 3 – Example of document format of roundtrip electrical efficiency

Test	Start state of EES system [a]	Electric power input	Electric energy input	Charged state of EES system	Electric power output	Net electric energy output	End state of EES system [a]	Roundtrip electrical efficiency
	(%)	(W)	(Wh)	(%)	(W)	(Wh)	(%)	(%)
Test 1	X	X	X	X	X	X	X	X
Test 2	X	X	X	X	X	X	X	X
Average	X	X	X	X	X	X	X	X

[a] Start and end (discharged) states have the same energy storage level for one charging~~/~~–discharging cycle measurement. The values for start and end state are typically 0 %, the value for charged state is typically 100 %.

6.6 Other system performance tests

6.6.1 System response test, step response time and ramp rate

The system response is measured, after confirming that the system is operating under the test state. The performance evaluation test shall be conducted by following the applicable standards for the response of the EES system.

The following typical evaluation procedures refer to IEC 62933-2-1.

The procedures are listed below. The EES system shall absorb or provide the ~~active~~ electric power according to the set point of rated input~~/~~ or output power. The set point and the input~~/~~ or output power at the POC shall be recorded with a data acquisition system at regular intervals of time, with appropriate time resolution.

The calculation of the step response times t_{sri} shall be carried out using Formula (1) in 5.6.1. The calculation of the ramp rates shall be carried out using Formula (2) in 5.6.2.

a) The EES system shall be charged or discharged to 50 % state of available energy or specified capacity value agreed upon between the system manufacturer and the customer.

b) The set point of electric power input or output shall be changed to zero. This set point shall be maintained until the electric power input or output is within ±2 % of the rated power input or output.

c) The set point of the electric power input shall be changed to rated power input. The set point value shall be maintained until the ~~active~~ electric power input at the POC is within ±2 % of rated power input. Step response time and ramp rate of this step shall be reported as t_{sr1} and $\mathrm{d}P/\mathrm{d}t_1$, respectively.

d) The set point of the electric power input shall be changed to zero. The set point value shall be maintained until the ~~active~~ electric power input at the POC is ±2 % of rated power input.

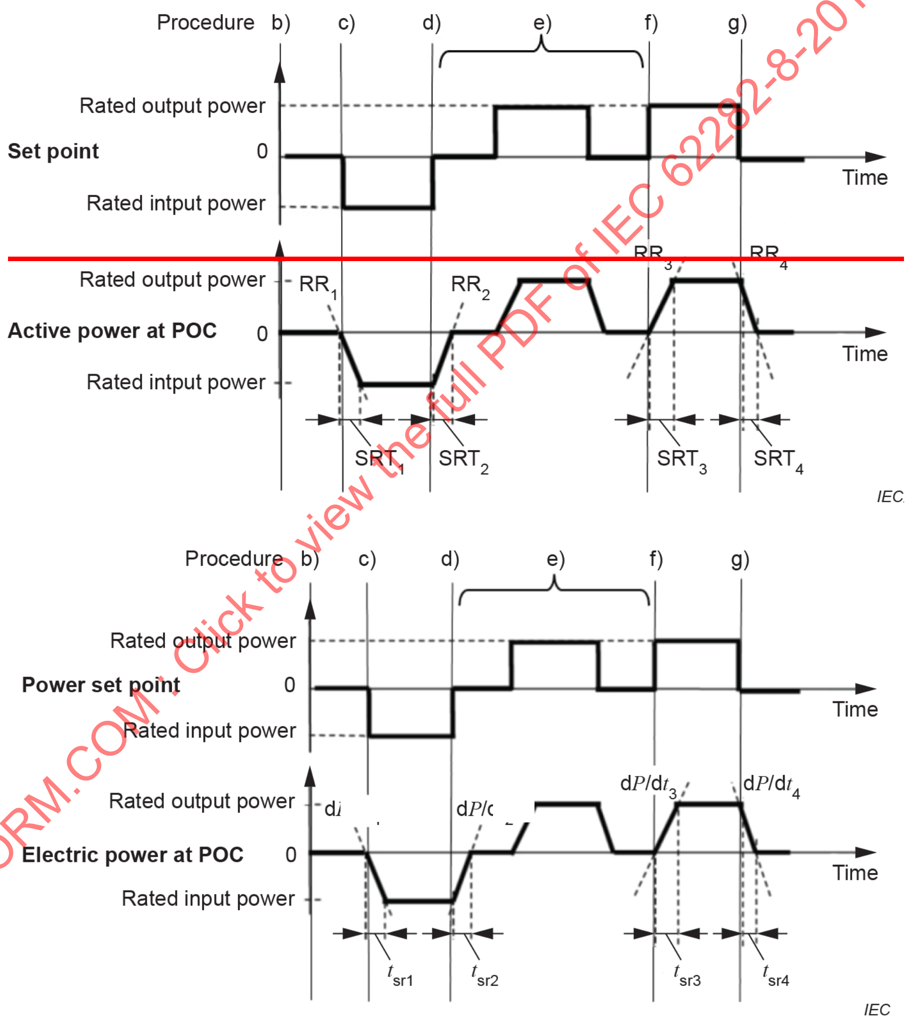
Step response time and ramp rate of this step shall be reported as t_{sr2} and dP/dt_2, respectively.

e) The EES system shall be discharged to 50 % state of available energy or specified capacity value agreed between the system manufacturer and user.

f) The set point of electric power output shall be changed to rated power output. The set point value shall be maintained until the ~~active~~ electric power output at the POC is within ±2 % of rated power output. Step response time and ramp rate of this step shall be reported as t_{sr3} and dP/dt_3, respectively.

g) The set point of electric power output shall be changed to zero. The set point value shall be maintained until the ~~active~~ electric power output at the POC is ±2 % of rated power output. Step response time and ramp rate of this step shall be reported as t_{sr4} and dP/dt_4, respectively.

Figure 5 shows the procedure listed from step b) to step g), step a) is omitted.



SOURCE IEC 62933-2-1:2017, Figure 7, modified.

Figure 5 – Step response test

6.6.2 Minimum switchover time test

The minimum switchover time is measured, after confirming that the system is operating under the test state. A typical test procedure for the switchover time of an EES system is listed below and shall apply (see Figure 6).

a) The specified charging and discharging power rates and the specified energy capacity levels for the test ~~are fixed by agreement~~ shall be agreed between the system manufacturer and the customer.

b) The tested EES system shall be charged or discharged to the specified capacity values.

c) The charging and discharging power rates at the POC shall be maintained until they are within ±2 % of their set ~~point values~~ points (see Figure 4).

d) Minimum switchover times from the charging phase to the discharging phase and from the discharging phase to charging phase shall be ~~respectively~~ measured and reported.

Figure 6 explains the minimum switchover time from charging phase to discharging phase t_{so1} and from discharging phase to charging phase t_{so2}.

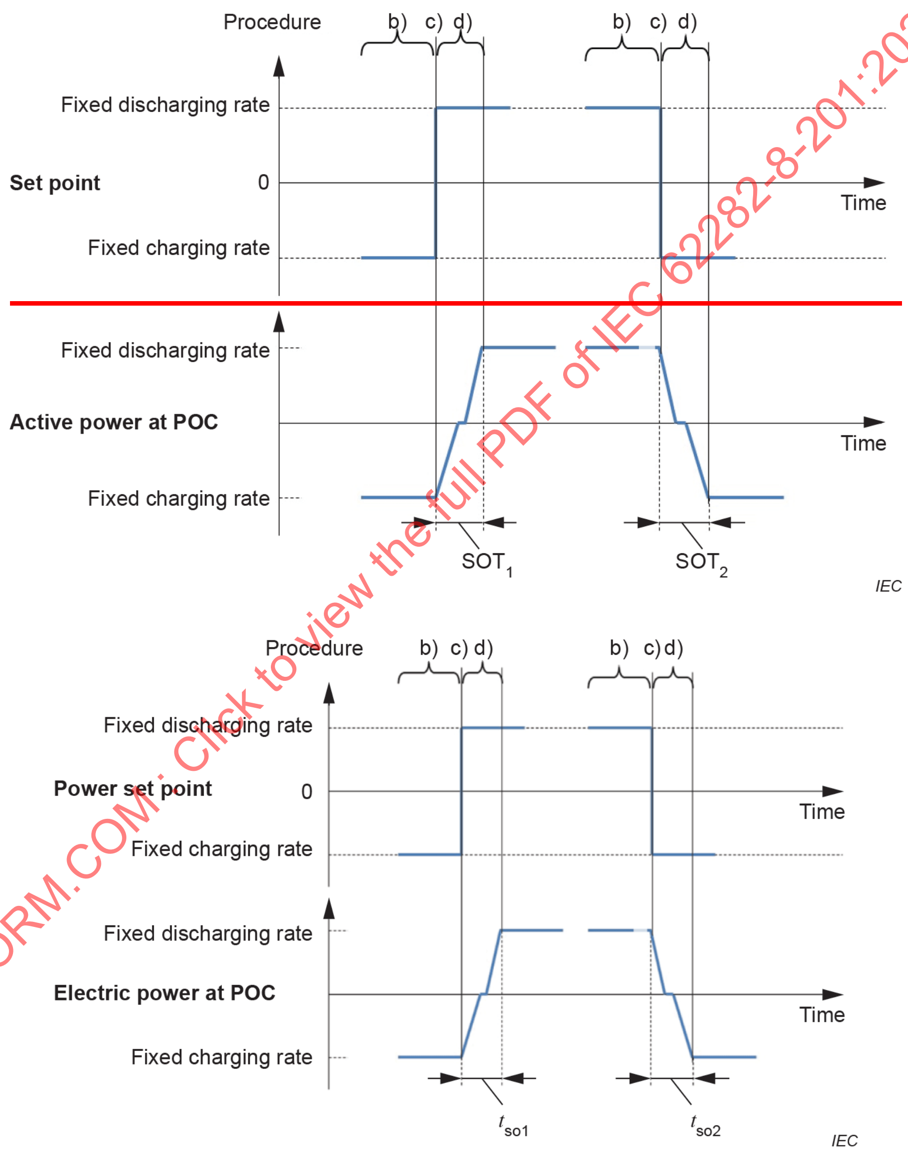


Figure 6 – Minimum switchover time test

6.6.3 ~~Quiescent~~ Stand-by state loss rate test

The ~~quiescent~~ stand-by state loss rate is measured, after confirming that the system is operating under the test state. The typical test procedure for the ~~quiescent~~ stand-by loss rate of an EES system is listed below and shall apply.

NOTE 1 The tests are similar to the IEC 62933-2-1 self-discharge test for EES systems.

NOTE 2 This test is not intended to determine hydrogen leakages, for which the relevant methods are given in IEC 62282-2-100 (fuel cell modules) and IEC 62282-3-100 (stationary fuel cell power systems).

a) The EES system shall be charged~~/~~ or discharged to 100 % of the rated energy capacity or specified energy capacity value agreed between the system manufacturer and the customer.

b) The EES system shall be kept at a ~~quiescent~~ stand-by state for the measurement period of self-discharging. The measurement period of self-discharging shall be chosen from among one hour, one day or one week or the time agreed between the system manufacturer and the user.

c) The electric energy input to the EES system shall be measured at the POC throughout the measurement period of self-discharging.

d) After completing the measurement period of self-discharging, the EES system shall be charged to the initial energy capacity level, and the electric energy input shall be measured at the POC.

e) The self-discharge power consumption shall be evaluated by using the sum of electric energy input measured in step c) and step d) in accordance with Formula (6). The electric energy input for re-charging shall be determined analogously to the net electric energy output using Formula (3).

$$P_{\text{el,loss}} = \frac{W_{\text{el,in}}}{t_{\text{loss}}} \tag{6}$$

where

$P_{\text{el,loss}}$ is the ~~quiescent~~ stand-by state loss rate (W);

$W_{\text{el,in}}$ is the sum of electric energy inputs during self-discharging in step c) and re-charging in step d) (Wh);

t_{loss} is the measurement time of self-discharging (h).

6.6.4 Heat input ~~rate~~ test

This test only applies to EES systems being equipped with a POC for heat input, using a heat-~~carrying~~ transfer fluid.

The heat input ~~rate~~ test of the EES system shall be performed using the electrical energy storage capacity ~~measurement~~ test ~~routine~~ in 6.2 and the ~~quiescent~~ stand-by loss rate test ~~routine~~ in 6.6.3. The heat input ~~rate~~ can be determined by using the measurement methods for external thermal input, as given in IEC 62282-3-200.

The heat input ~~rate~~ shall be determined separately and reported for the charging phase ~~by using the routine~~ in accordance with 6.2 b), for the discharging phase ~~by using the routine~~ in accordance with 6.2 c), and for the storage phase ~~by using the routine~~ in accordance with 6.6.3. If during one of these phases no heat input occurs, the test of that phase can be omitted. The measured values of the heat input ~~rate~~ shall be compared to specified values, if available. The test operating conditions shall also be reported ~~exactly~~, comprising the temperature ~~levels~~ of the heat transfer fluid ~~inlet~~ input and ~~outlet~~ output, and the ~~heat fluid~~ respective flow rate. If other suitable heat input ~~rate~~ test methods are applied, the test methods and conditions shall be reported.

6.6.5 Recovered heat output ~~rate~~ test

This test only applies to EES systems being equipped with a POC for recovered heat output, using a heat ~~carrying~~ transfer fluid.

The recovered heat output ~~rate~~ test of the EES system shall be performed using the electrical energy storage capacity ~~measurement~~ test ~~routine~~ in 6.2 and the ~~quiescent~~ stand-by loss rate test~~ routine~~ in 6.6.3. The recovered heat output~~ rate~~ can be determined by using the measurement methods for recovered thermal power output, as given in IEC 62282-3-200.

The recovered heat output~~ rate~~ shall be determined separately and reported for the charging phase~~ using the routine~~ in accordance with 6.2 b) , for the discharging phase~~ using the routine~~ in accordance with 6.2 c), and for the storage phase~~, using the routine~~ in accordance with 6.6.3. If during one of these phases no recovered heat output occurs,~~ the referring~~ this test can be omitted. The measured values of the recovered heat output~~ rate~~ shall be compared to the specified values. The test operating conditions shall also be reported~~ exactly~~, comprising the temperature levels of the heat fluid inlet and outlet and the heat fluid flow rate. If other suitable recovered heat output~~ rate~~ test methods are applied, the test methods and conditions shall be reported.

6.6.6 Hydrogen input and output rate test

This test only applies to EES systems being equipped with a POC for hydrogen input and output, which are connected to a hydrogen supply infrastructure.

The hydrogen input and output rate test of the EES system shall be performed by measuring the hydrogen mass flow into and out of the system, using the roundtrip electrical efficiency test routine in 6.5.2.2. The hydrogen input and output rate can be determined by using the measurement methods for fuel input, as given in IEC 62282-3-200.

The hydrogen input rate shall be determined for the charging phase by using the routine in 6.5.2.2 a). The hydrogen output rate shall be determined for the discharging phase by using the routine in 6.5.2.2 b). The measured values of the hydrogen input and output rate shall be compared to specified values, if available. The test operating conditions shall also be reported, comprising the temperature and the pressure of the hydrogen at the POC.

6.6.7 Acoustic noise level test

The acoustic noise level is measured, after confirming that the system is operating under the test state.~~ The performance evaluation of acoustic noise level in test standards ISO 3746, ISO 9614-1 and ISO 11204 shall be followed as appropriate.~~ This test shall be conducted in accordance with ISO 3746, ISO 9614-1 or ISO 11204 as appropriate.

6.6.8 Total harmonic distortion test

Total harmonic distortion shall be measured and reported for EES systems that are connected to an AC grid. IEC 61000-4-7 and IEC 61000-4-13 provide measurement guidance.

6.6.9 Discharge water quality test

Discharge water quality is measured, after confirming that the system is operating under the test state and intended water discharge takes place. Any appropriate methods for water quality evaluation, for example ISO 15839, ISO 17381 and IEC 62282-3-201, apply.

6.7 Component performance test

6.7.1 Electrolyser performance test

In addition to the tests specified in 6.6, the hydrogen production rate, the electric power and the water consumption are measured for the electrolyser or the reversible cell module in electrolysis mode. The boundary of the electrolyser or the reversible cell module in the tested EES system shall be agreed between the system manufacturer and the customer. The respective performance evaluation methods of~~ ISO 22734-1 or ISO 22734-2~~ ISO 22734:2019 for the hydrogen production rate and the electric power, IEC 62282-8-101 (solid oxide electrolysis cells) or IEC 62282-8-102 (polymer electrolyte membrane cells) for the electric power of single cell and stack, and IEC 62282-3-200 for the water consumption apply.

As an optional property evaluation test, the purge gas consumption is measured for the electrolyser or the reversible cell module in electrolysis mode. The respective performance evaluation method of IEC 62282-3-200 applies.

The measurements shall be conducted under the test state and under the rated operating conditions, using the referenced standards in Table 4.

For electrolysers without suitable performance evaluation test standards, the applied test method and conditions shall be ~~reported and they shall be~~ recommended by the manufacturer and documented in the test report (see Clause 7).

Table 4 – Additional parameters measured on the electrolyser or the reversible cell module in electrolysis mode

Parameter	Definition	Reference
Hydrogen production rate	Electrolytic hydrogen production rate (kg/h)	~~ISO 22734-1~~ ~~ISO 22734-2~~ ISO 22734:2019
Electric power	Electric power input (W)	~~ISO 22734-1~~ ~~ISO 22734-2~~ ~~For single cell and stack~~ ISO 22734:2019 IEC 62282-8-101 IEC 62282-8-102
Water consumption[a]	Water consumption rate (kg/h)	
Purge gas consumption	Amount of supplied inert or dilution gas (l/min)	IEC 62282-3-200
~~NOTE~~ [a] Water consumption of the electrolyser for the electrolysis and others, if ~~required~~ used (i.e. cooling water).		

6.7.2 Hydrogen storage performance test

In addition to the tests specified in 6.6, the hydrogen storage rate, the operating power and the consumed electricity for storing the unit amount of hydrogen operated under the test state and the rated operating conditions are measured for the hydrogen storage components. Any appropriate methods for evaluating hydrogen storage performance~~, using the referenced standards in Table 4,~~ shall apply in accordance with Table 5 depending on the storage types of hydrogen. ISO 16111 is referenced as a method for evaluating the hydrogen storage capacity.

For the hydrogen storage without suitable performance evaluation test standards, the applied test method and conditions shall be ~~reported and they shall be~~ recommended by the manufacturer and documented in the test report (see Clause 7).

Table 5 – Additional parameters measured on the hydrogen storage component

Parameter	Definition	Reference
Storage rate	Rate of storing hydrogen (kg/h)	For storage capacity: ~~ISO 19884~~ ISO 16111
Operating power	Electric power required for operation (W/kg)	
Consumed electricity	Electricity for storing unit amount of hydrogen (Wh/kg)	

6.7.3 Fuel cell performance test

In addition to the tests specified in 6.6, the electric power, the thermal power, the electrical efficiency and the overall efficiency are measured for the fuel cell or the reversible cell module in fuel cell mode. The respective performance evaluation methods of IEC 62282-3-200 or IEC 62282-3-201 ~~(for fuel cell systems)~~ or of IEC 62282-8-101 or IEC 62282-8-102 ~~(for single cell and stack performance)~~ apply.

As an optional property evaluation test, the purge gas consumption is measured for the fuel cell or the reversible cell module in fuel cell mode. The respective performance evaluation method of IEC 62282-3-200 applies.

The measurements shall be conducted under the test state and under the rated operating conditions, using the referenced standards in Table 6.

For the fuel cells without suitable performance evaluation test standards, the applied test method and conditions shall be ~~reported and they shall be~~ recommended by the manufacturer and documented in the test report (see Clause 7).

Table 6 – Additional parameters measured on the fuel cell or the reversible cell module in fuel cell mode

Parameter	Definition	Reference
Electric power	Net electric power output (W)	IEC 62282-3-200 IEC 62282-3-201
Electrical efficiency	Ratio of electric power output and fuel power input (%)	
Thermal power	Recovered thermal power output (W)	IEC 62282-3-201
Overall efficiency	Ratio of all useful power outputs and fuel power input (%)	
Purge gas consumption	Amount of supplied inert or dilution gas (m^3/s)	IEC 62282-3-200

6.7.4 Water management system performance test

In addition to the tests specified in 6.6, the water input flow rate (l/min) and the electric power input (W) are measured for the water management system. Use appropriate methods for evaluating fluid flow in closed conduits, for example ISO 4064-1 and ISO 4064-2~~, shall apply~~. For the devices without suitable performance evaluation test standards, the applied test method and conditions shall be reported and they shall be recommended by the system manufacturer.

As optional ~~property~~ performance evaluation tests, the water storage capacity (m^3, l), and the water purification quality (e.g. conductivity in µS/cm) are measured ~~for the water management system~~. Use standards of fluid flow in closed conduits for measuring the water storage capacity, ~~the standards of fluid flow in closed conduits,~~ for example ISO 4064-1 and ISO 4064-2~~, apply~~.

For the water management systems without suitable performance evaluation test standards, the applied test method and conditions shall be ~~reported, and they shall be~~recommended by the manufacturer and documented in the test report (see Clause 7).

~~For the water purification property of the water management system,~~ Use appropriate standards ~~regarding~~ for the determination of water purification quality, for example ISO 7888 (determination of electrical conductivity) ~~shall apply~~. Information about the typical impurities that are expected to affect the components' properties considerably shall be provided by the system manufacturer. ~~It is to be noted that~~ These properties change during operation, so attention is ~~required~~ important.

6.7.5 Battery performance test

In addition to the tests specified in 6.6, the charging capacity is measured for the battery ~~which is one of the electric input/output and storage components~~. Also, the electric power input, the electric power output and the charge–discharge efficiency operated under the test state and the rated operating conditions are measured.

The performance evaluation test standards for the relevant type of battery apply; for example, IEC 61427-1 and IEC 61427-2 particularly for renewable energy storage.

For batteries without suitable performance-evaluation test standards, the applied test method and conditions shall be ~~reported and they shall be~~ recommended by the manufacturer and documented in the test report (see Clause 7).

6.7.6 Oxygen storage performance test

In addition to the tests specified in 6.6, the oxygen storage capacity, the oxygen storage rate, the operating power and the consumed electricity for storing the unit amount of oxygen ~~storage and the efficiency for oxygen storage~~ operated under the test state and the rated operating conditions are measured for the oxygen storage component. The applied measuring method and conditions shall be ~~reported and they shall be~~ recommended by the manufacturer and documented in the test report (see Clause 7).

7 Test reports

7.1 General

Test reports shall accurately, clearly and objectively present sufficient information to demonstrate that all the objectives of the tests have or have not been attained.

7.2 Report items

The report shall present at least the following information:

a) title of the report;

b) authors of the report;

c) date of the report;

d) standard number, test procedure number;

e) location of the test;

f) tested system data (see 7.3 for details);

g) test conditions (see 7.4 for details);

h) test data (see 7.5 for details).

7.3 Tested system data description

The tested EES system data shall include at least the following information:

a) product name and brand name of the system;
b) constitution of the system;
c) definition of the boundary for the tested EES system;
d) type of electrolyser ~~and/~~or reversible cell;
e) type of fuel cell;
f) type of hydrogen storage (if included);
g) type of battery (if included);
h) type of oxygen storage (if included).

7.4 Test condition description

The test condition description shall include at least the following information:

a) name of person or persons conducting the test;
b) instruments, calibration record;
c) definition of the operating state;
d) test procedure;
e) data acquisition method.

7.5 Test data description

The test data shall include at least the following information:

a) title of the test or tests;
b) test operating conditions;
c) test results;
d) ambient conditions;
e) uncertainty evaluation (see 7.6 for details).

If system operation requires external energies, such as heating, cooling and the like, and such energies are not incorporated in the performance tests, the energies and their amounts shall be reported under b).

7.6 Uncertainty evaluation

Uncertainties of instruments shall be reported. If necessary, variation of measurements and~~/or~~ measurement uncertainties calculated from the variation of measurements and uncertainties of instruments should be reported (see ISO/IEC Guide 98-3).

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~~4 Under preparation. Stage at the time of publication: IEC FDIS 60050-485:2019.~~

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IEC 62282-8-201

Edition 2.0 2024-07

INTERNATIONAL STANDARD

NORME INTERNATIONALE

colour inside

Fuel cell technologies –
Part 8-201: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of power-to-power systems

Technologies des piles à combustible –
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IEC 62282-8-201:2024-07(en-fr)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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FUEL CELL TECHNOLOGIES –

Part 8-201: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of power-to-power systems

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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IEC 62282-8-201 has been prepared by IEC technical committee 105: Fuel cell technologies. It is an International Standard.

This second edition cancels and replaces the first edition published in 2020. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) consideration of systems connected to hydrogen supply infrastructure (hydrogen grids, vessels, caverns or pipelines);
b) hydrogen input and output rate is added in the system parameters (5.10);
c) electric energy storage capacity test is revised (6.2);

d) roundtrip electrical efficiency test is revised (6.5);

e) hydrogen input and output rate test is added (6.6.6).

The text of this International Standard is based on the following documents:

Draft	Report on voting
105/1034/FDIS	105/1050/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 62282 series, published under the general title *Fuel cell technologies*, can be found on the IEC website.

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

- reconfirmed,
- withdrawn, or
- revised.

IMPORTANT – The "colour inside" logo on the cover page of this document 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

This part of IEC 62282 specifies performance evaluation methods for electric energy storage systems using hydrogen that employ electrochemical reactions both for water and steam electrolysis and electric power generation.

NOTE Heat generation can be a secondary purpose.

This document is intended for power-to-power systems which typically employ a set of electrolyser and fuel cell, or a reversible cell for devices of electric charge and discharge.

A typical target application of the electric energy storage systems using hydrogen is in the class of energy intensive electric energy storage. The systems are recognized as critically useful for the relatively long-term power storage operation, such as efficient storage and supply of the renewable power derived electric energy and grid stabilization.

The IEC 62282-8 series aims to develop performance test methods for power storage and buffering systems based on electrochemical modules (combining electrolysis and fuel cells, in particular reversible cells), taking into consideration both options of re-electrification and substance (and heat) production for sustainable integration of renewable energy sources.

Under the general title Energy storage systems using fuel cell modules in reverse mode, the IEC 62282-8 series consists of the following parts:

- IEC 62282-8-101: Test procedures for the performance of solid oxide single cells and stacks, including reversible operation
- IEC 62282-8-102: Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation
- IEC 62282-8-103[1]: Alkaline single cell and stack performance including reversible operation
- IEC 62282-8-201: Test procedures for the performance of power-to-power systems
- IEC 62282-8-202[2]: Power-to-power systems – Safety
- IEC 62282-8-301: Power to methane energy systems based on solid oxide cells including reversible operation – Performance test methods

As a priority dictated by the emerging needs for industry and opportunities for technological development, IEC 62282-8-101, IEC 62282-8-102 and IEC 62282-8-201 were initiated jointly and firstly. These parts are presented as a package to highlight the need for an integrated approach as regards the system's application (i.e. a solution for energy storage) and its fundamental constituent components (i.e. fuel cells operated in reverse or reversing mode).

1 Future project.

2 Future project.

FUEL CELL TECHNOLOGIES –

Part 8-201: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of power-to-power systems

1 Scope

This part of IEC 62282 defines the evaluation methods of typical performances for electric energy storage systems using hydrogen. It is applicable to the systems that use electrochemical reaction devices for both power charge and discharge. This document applies to systems that are designed and used for service and operation in stationary locations (indoor and outdoor).

The conceptual configurations of the electric energy storage systems using hydrogen are shown in Figure 1 and Figure 2.

Figure 1 shows the system independently equipped with an electrolyser module and a fuel cell module. Figure 2 shows the system equipped with a reversible cell module.

Indispensable components are an electrolyser module and a fuel cell module, or a reversible cell module, an overall management system (which includes a data interface and can include a pressure management), a thermal management system (which can include a thermal storage), a water management system (which can include a water storage) and a purge gas supply (inert gas, practically neither oxidizing nor reducing).

NOTE 1 Indispensable components are indicated by bold lines in Figure 1 and Figure 2.

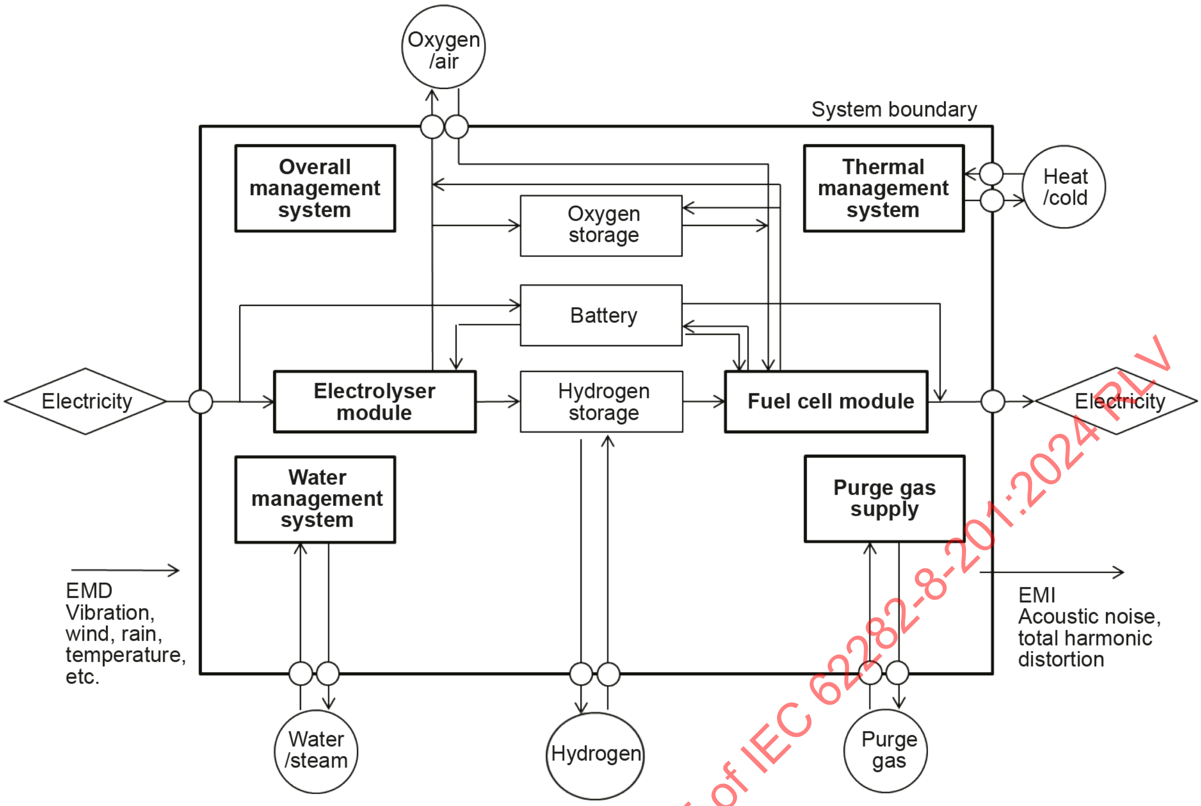
The system can be equipped with either a hydrogen storage or a connection to an external hydrogen supply infrastructure or a combination of both. There can be a battery and an oxygen storage, as optional components.

The electrolyser module can comprise one or more electrolysers whether or not of the same type. Depending on the operating conditions and considering the operation history, the overall management system can command the concurrent operation of the electrolysers. The fuel cell module can comprise one or more fuel cells whether or not of the same type. Depending on the operating conditions and considering the operation history, the overall management system can command concurrent operation of the fuel cells. The reversible cell module can comprise one or more reversible cells whether or not of the same type. The fuel cell module can comprise one or more fuel cells whether or not of the same type. Depending on the operating conditions and considering the operation history, the overall management system can command concurrent operation of the reversible cells.

The performance measurement is executed in the defined area surrounded by the bold outside solid line (system boundary).

NOTE 2 In the context of this document, the term "reversible" does not refer to the thermodynamic meaning of an ideal process. It is common practice in the fuel cell community to call the operation mode of a cell that alternates between fuel cell mode and electrolysis mode "reversible".

This document is intended to be used for data exchanges in commercial transactions between the system manufacturer and customer. Users of this document can selectively execute test items suitable for their purposes from those specified in this document.



Key

EMD electromagnetic disturbance

EMI electromagnetic interference

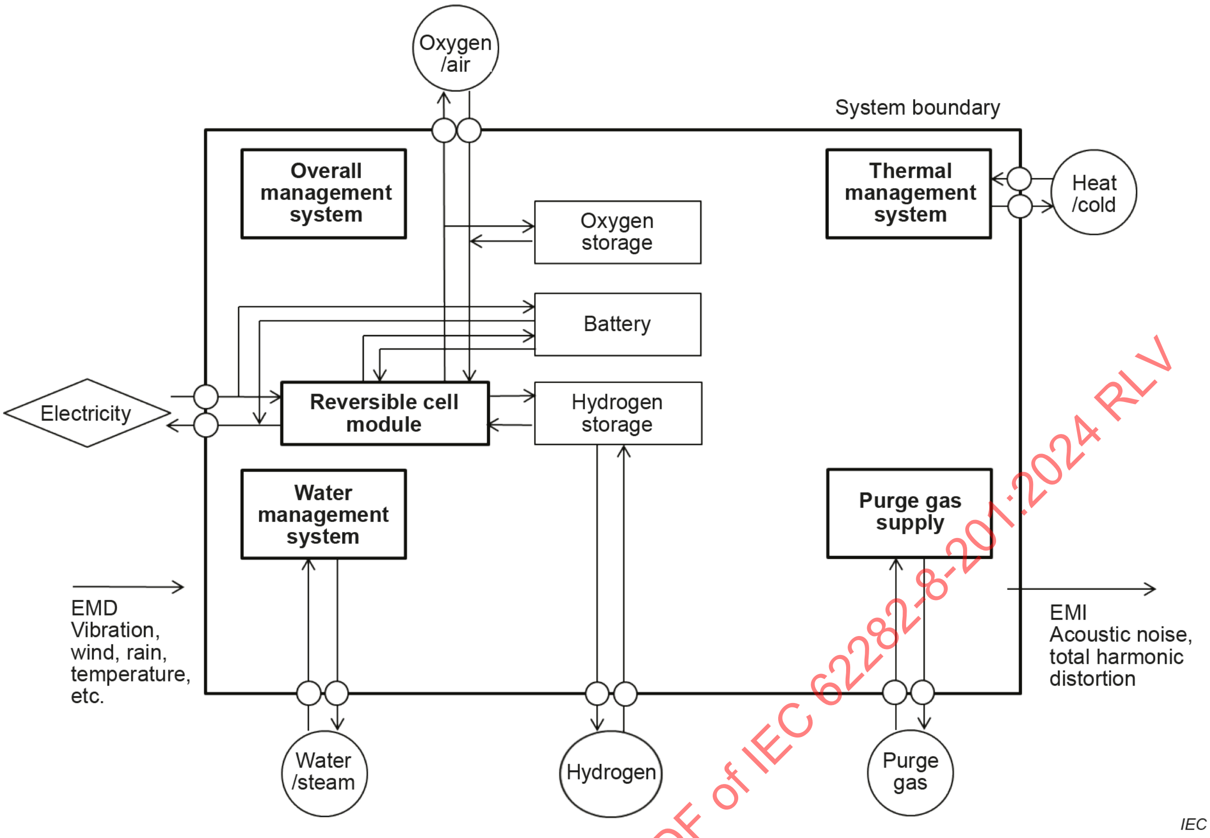
NOTE 1 Overall management system, thermal management system, water management system and purge gas supply can have the relation with electrolyser, fuel cell, battery, hydrogen storage and oxygen storage, and also can have the relation with one another.

NOTE 2 Other fluid or energy in- or outputs, depending on the used electrolyser and fuel cell types, can be considered.

NOTE 3 The electricity input and output can be DC or AC or both. Power conditioning sub-systems are usually used.

NOTE 4 There can be more than one electricity point of connection for input or output or both.

Figure 1 – System configuration of electric energy storage system using hydrogen – Type with electrolyser and fuel cell



Key

EMD electromagnetic disturbance

EMI electromagnetic interference

NOTE 1 Overall management system, thermal management system, water management system and purge gas supply can have the relation with reversible cell, battery, hydrogen storage and oxygen storage, and also can have the relation with one another.

NOTE 2 Other fluid or energy in- or outputs, depending on the used electrolyser and fuel cell types, can be considered.

NOTE 3 The electricity input and output can be DC or AC or both. Power conditioning sub-systems are usually used.

NOTE 4 There can be more than one electricity point of connection for input or output or both.

Figure 2 – System configuration of electric energy storage system using hydrogen – Type with reversible cell

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

IEC 61427-2, *Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 2: On-grid applications*

IEC 62282-3-200, *Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods*

IEC 62282-3-201, *Fuel cell technologies – Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems*

IEC 62282-8-101, *Fuel cell technologies – Part 8-101: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of solid oxide single cells and stacks, including reversible operation*

IEC 62282-8-102, *Fuel cell technologies – Part 8-102: Energy storage systems using fuel cell modules in reverse mode – Test procedures for the performance of single cells and stacks with proton exchange membrane, including reversible operation*

IEC 62933-2-1:2017, *Electrical energy storage (EES) systems – Part 2-1: Unit parameters and testing methods – General specification*

ISO/IEC Guide 98-3, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO 3746, *Acoustics – Determination of sound power levels and sound energy levels of noise sources using sound pressure – Survey method using an enveloping measurement surface over a reflecting plane*

ISO 9614-1, *Acoustics – Determination of sound power levels of noise sources using sound intensity – Part 1: Measurement at discrete points*

ISO 11204, *Acoustics – Noise emitted by machinery and equipment – Determination of emission sound pressure levels at a work station and at other specified positions applying accurate environmental corrections*

ISO 16111, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

ISO 19880-1, *Gaseous hydrogen – Fuelling stations – Part 1: General requirements*

ISO 19881, *Gaseous hydrogen – Land vehicle fuel containers*

ISO 19882, *Gaseous hydrogen – Thermally activated pressure relief devices for compressed hydrogen vehicle fuel containers*

ISO 22734:2019, *Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

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

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

3.1.1
electric energy storage
EES
installation able to store electric energy or which converts electric energy into another form of energy and vice versa, while storing energy

3.1.2
electric energy storage system
EES system
installation with defined electrical boundaries, comprising at least one EES, whose purpose is to extract electric energy from the electric power system, store this energy in some manner and inject electric energy into the electric power system and which includes civil engineering works, energy conversion equipment and related ancillary equipment

Note 1 to entry: The EES system is controlled and coordinated to provide services to the electric power system operators or to the electric power system users.

Note 2 to entry: In some cases, an EES system can require an additional energy source during its discharge, providing more energy to the electric power system than the energy it stores.

[SOURCE: IEC 62933-1:2018, 3.2, modified – In the definition, "grid connected" and "internally" have been deleted, and "which extracts" has been replaced by "whose purpose is to extract". Note 2 to entry has been shortened and Note 3 to entry deleted.]

3.1.3
EES system using hydrogen
EES system comprising at least one EES using hydrogen, whose purpose is to extract electric energy from the electric power system, store this energy as hydrogen and inject electric energy into the electric power system, using hydrogen as a fuel

Note 1 to entry: The conceptual configurations of the EES system using hydrogen are referred to in Clause 1.

3.1.4
battery
EES device for electrochemically storing electricity with electricity charge and discharge functions

Note 1 to entry: Batteries are typically employed for absorbing short-term fluctuating electricity input combined with hydrogen storage of an EES system using hydrogen.

3.1.5
electrolyser
electrochemical device that converts water or steam to hydrogen and oxygen by electrolysis reaction

Note 1 to entry: Electrolysers include alkaline water electrolysis device, polymer electrolyte membrane water electrolysis device, solid oxide electrolysis cell device, and other devices of similar type.

3.1.6
environment
surroundings in which an EES system using hydrogen exists, including air, water, land, natural resources, flora, fauna, humans, and their interrelation

3.1.7
fuel cell
electrochemical device that converts the chemical energy of a fuel and an oxidant to electric energy (DC power), heat and reaction products

Note 1 to entry: The fuel and oxidant are typically stored outside of the fuel cell and transferred into the fuel cell as they are consumed.

[SOURCE: IEC 60050-485:2020, 485-08-01]

3.1.8
thermal management system
subsystem of the EES system using hydrogen, for controlling the thermal storage and thermal fluid flows in the system and its POCs (if applicable)

Note 1 to entry: Typically, heat is utilized among the various items of system equipment. An example of the mutual heat utilization is where the exothermic reaction heat of the fuel cell is conveyed to an electrolysis cell, in particular a solid oxide electrolysis cell for endothermic consumption.

3.1.9
hydrogen storage
component of the EES system using hydrogen, for storing hydrogen that is produced by water or steam electrolysis in or supplied to the system

Note 1 to entry: There are several kinds of hydrogen storage equipment depending on the hydrogen storage principles. They include low- and high-pressure gas, liquid, hydrogen-absorbing alloy (hydrogen absorbed in reversible metal hydride), non-metal hydrides and others.

3.1.10
hydrogen supply infrastructure
assembly of hydrogen carrying and storing devices providing connection points to hydrogen appliances, which supply hydrogen to the appliance or absorb hydrogen delivered by the appliance

3.1.11
limit operating conditions
conditions not to be exceeded for operating the EES system normally and safely

Note 1 to entry: They are recommended by the EES system manufacturer considering the system characteristics.

3.1.12
net electric energy output
usable electric energy output from the EES system using hydrogen, which is able to serve for the user's purpose, excluding internal and external electric energy dissipation of the system

Note 1 to entry: The internal and external electric dissipation of the EES system is typically electric energy loss from the equipment operations and connections.

Note 2 to entry: The net electric energy output is the difference between the electric energy outputs and inputs at all POCs.

3.1.13
net electric power
power output of the EES system and available for external use

Note 1 to entry: The net electric power output is the difference between the electric power outputs and inputs at all POCs.

3.1.14
operating conditions
conditions at which the tested system, more specifically each item of equipment of the tested EES system, is operated, and including physical conditions such as range of ambient temperatures, pressure, radiation levels, humidity and atmosphere

3.1.15
operating state
state at which the tested system, more specifically each item of equipment of the tested EES system, is operated at specified conditions

3.1.16
overall management system
subsystem of the EES system using hydrogen, served for monitoring and controlling the EES system using hydrogen, including all equipment and functions for acquisition, processing, transmission, and display of the necessary process information

Note 1 to entry: The overall management system also includes a subsystem containing an arrangement of hardware, software, and propagation media to allow the transfer of messages from one EES system using hydrogen component or subsystem to another one, including the data interface with external links.

Note 2 to entry: Generally, the control subsystem may be connected to the primary POC (just for data exchange) and it can comprise the communication subsystem and the protection subsystem.

Note 3 to entry: The protection subsystem includes one or more items of protection equipment, one or more instrument transformers, transducers, wiring, one or more tripping circuits, one or more auxiliary supplies. Depending upon the principle or principles of the protection system, it may include one end or all ends of the protected section and, possibly, automatic reclosing equipment.

3.1.17
oxygen storage
component of the EES system using hydrogen, for storing oxygen that is produced by water or steam electrolysis in or supplied to the EES system

Note 1 to entry: Oxygen storage is equipped, if needed.

3.1.18
point of connection
POC
point where an EES system using hydrogen is connected to a supply or extraction exterior to the system

Note 1 to entry: Generally, POCs are electricity, heat, water, hydrogen, oxygen and air connection points. They are shown as open circles on the EES system boundary (thick solid-line square) in Figure 1 and Figure 2.

3.1.19
stand-by state
operating state of the EES system, in which the EES system is partly or fully charged and no intended charging and discharging of the stored energy, except self-discharging, takes place

3.1.20
rated operating conditions
conditions which are applied for standard operation of equipment or systems

Note 1 to entry: Rated operating conditions are recommended by the equipment or EES system manufacturers considering the characteristics of the equipment or system.

3.1.21
rated input conditions
conditions specified by the manufacturer, at which the tested EES system absorbs electric power input at the POC

Note 1 to entry: The rated input conditions include the rates of net electric power, heat, water flow, oxygen flow and air flow.

3.1.22
rated output conditions
conditions specified by the manufacturer, at which the tested EES system delivers electric power output at the POC

Note 1 to entry: The rated output conditions include the rates of net electric power, heat, water flow, oxygen flow and air flow.

3.1.23
rated test conditions
specific boundary conditions at which the tested EES system is operated

Note 1 to entry: Rated test conditions are agreed between the EES system manufacturer and customer.

3.1.24
reversible cell
electrochemical device that is able to operate as a fuel cell or as an electrolyser, alternatively

Note 1 to entry: The term "reversible" in this context does not refer to the thermodynamic principle of an ideal process.

3.1.25
roundtrip electrical efficiency
electric energy discharged measured on the primary POC divided by the electric energy absorbed, measured on all the POCs (primary and auxiliary), over one EES system standard charging–discharging cycle under specified operating conditions

Note 1 to entry: The auxiliary POC is used for electricity supply of auxiliary components and devices such as instrumentation, controls, monitoring and safety functions.

3.1.26
operation history
record of the operating conditions of the system

3.1.27
steady state
state of an EES system in which the relevant characteristics remain constant with time

[SOURCE: IEC 60050-485:2020, 485-21-05, modified – In the definition, “physical” has been replaced with “EES”.]

3.1.28
switchover time
time that is required to switch an EES system using hydrogen from a specified charging phase to a specified discharging phase or vice versa

Note 1 to entry: This can be of relevance in case grid service is required to be performed with the EES system. It comprises the time that is required to go from one operating point in either charging or discharging operation to stand-by state, purging of gas lines if applicable, setting of auxiliary components (valves, heaters, compressors, etc.) if applicable and to go to an operating point in the opposite operating phase (discharging or charging).

3.1.29
test state
state of the tested EES system that is consistent with the objective of the evaluation

3.1.30
tested system
EES system defined by its boundary to the environment that is in accordance with the objective of the evaluation

3.1.31
water management system
subsystem of the EES system using hydrogen, for controlling the water flow, the steam flow or both in the EES system

Note 1 to entry: Water management system includes the controlling mechanisms of water inlet, transport, purifying (if applicable), and drain.

3.2 Symbols

Table 1 lists the symbols and units that are used in this document.

Table 1 – Symbols

Symbol	Definition	Unit	Formula	Figure
k	Coverage factor			
$m_{\mathrm{H2,in}}$	Hydrogen mass supplied to the system at the POC	g	(4)	
n	Number of measurements until discharge completion		(3), (4)	
P_{el}	Electric power at the POC	W	(2)	
$P_{\mathrm{el,loss}}$	Stand-by state loss rate	W	(6)	
$P_{\mathrm{el,in}}$	Net electric power input	W		
$P_{\mathrm{el,out}}$	Net electric power output	W	(3)	
$\mathrm{d}P/\mathrm{d}t$	Ramp rate	W/s	(2)	Figure 5
$P_{\mathrm{th,in}}$	Heat input	W		
$P_{\mathrm{th,out}}$	Heat output	W		
$q_{m,\mathrm{H2,in}}$	Hydrogen mass flow into the system at the POC	g/s	(4)	
$q_{m,\mathrm{H2,out}}$	Hydrogen mass flow out of the system at the POC	g/s		
t_0	Time when the system, which is in steady state, receives the set point value	s	(1)	Figure 4
t_1	Time when the electric power at the POC becomes less than 90 % for negative state or higher than 10 % for positive state of the set point value	s	(2)	Figure 4
t_2	Time when the electric power at the POC becomes less than 10 % for negative state or higher than 90 % for positive state of the set point value	s	(2)	Figure 4
t_3	Time when the electric power at the POC reaches within 2 % of the set point value	s	(1)	Figure 4
t_{loss}	Measurement time of self-discharging	h	(6)	
t_{so}	Switchover time	s		Figure 6
t_{sr}	Step response time	s	(1)	Figure 5
W_{el}	Electric energy storage capacity	Wh	(3)	
$W_{\mathrm{el,in}}$	Electric energy input	Wh	(5), (6)	
$W_{\mathrm{el,out}}$	Net electric energy output	Wh	(3)	
Δt	Sampling time of measurement	h, s	(3)	
η_{el}	Roundtrip electrical efficiency	%	(5)	

4 Measurement instruments and measurement methods

4.1 General

For measuring certain properties of the tested EES system, the configuration of its components and the boundary conditions to the environment shall be determined first.

Attention is required to clearly define the tested EES system. The components which the tested EES system includes and the conditions of the test environment at all points of connection (POC) shall be defined. The POCs are input and output connections for electricity, heat, water, hydrogen, oxygen and air. The boundary conditions for all POCs shall be defined.

Secondly, the test state of the EES system shall be defined. The test state of the EES system means the operating levels compared to the maximum capability of either the EES system or one of its components at the time of test execution.

Then the operating conditions for the test shall be defined. They shall be agreed between the ESS system manufacturer and the customer.

During execution of the tests, the operating times shall be noted. They are the electric input time, the electric output time, the input-and-output stand-by period, and combination patterns thereof. The operation history and the actual operating time of the system affects the evaluation of the EES system performance, therefore the history of the operating times of the EES system before executing the test shall also be reported.

Where it is unfeasible to perform measurements of electric power or media flow at full scale due to large system size, for safety related reasons or lack of suitable instrumentation, measurements may be performed at sub-system level. Such measurements shall allow derivation of data representative of measurements at full system size. The measurement concept applied shall be detailed in the test report (see 7.4).

4.2 Instrument uncertainty

The expanded uncertainty of each measuring instrument (coverage factor k = 2) at the time of calibration or that estimated from the class of instrument shall meet the following requirements:

– electric power: ±2 % of reading;
– current: ±1 % of reading;
– voltage: ±1 % of reading;
– mass flow: ±1 % of reading;
– ambient temperature: ±1 K;
– ambient pressure: ±0,1 kPa;
– ambient relative humidity: ±5 %.

Instruments that satisfy the above requirements shall be used. ISO/IEC Guide 98-3 shall apply.

4.3 Measurement plan

The components' configuration, the boundary conditions to the environment of the tested EES system and the test state shall be clearly defined. The test state shall be considered according to the application and usage. Also, the test phases, which are charge, storage and discharge illustrated in Figure 3, should be considered.

The rated and the limit operating conditions for the tested EES system are confirmed between the system manufacturer and the customer. The rated and the limit operating conditions for each component shall be established from the component manufacturers' specifications.

Then the sequence of the measurements shall be planned. It shall be considered that certain properties of some components relate to the conditions or the settings for other components. For example, the operating state of the hydrogen storage capacity relates to the operating conditions settings of the electrolyser. Also, attention should be paid to the fact that some properties can change considerably during the measurement. For example, the electric power input can vary during a charging phase. The test state shall be clearly defined and the property changes during the measurement shall be identified. For setting up the measurement methods and instruments, instrument uncertainty and permissible variation shall be checked and reported. The actions to be made before executing the measurement are summarized in Table 2.

After confirming that the EES system is operating under the test state, the measurement for testing the EES system performance is executed.

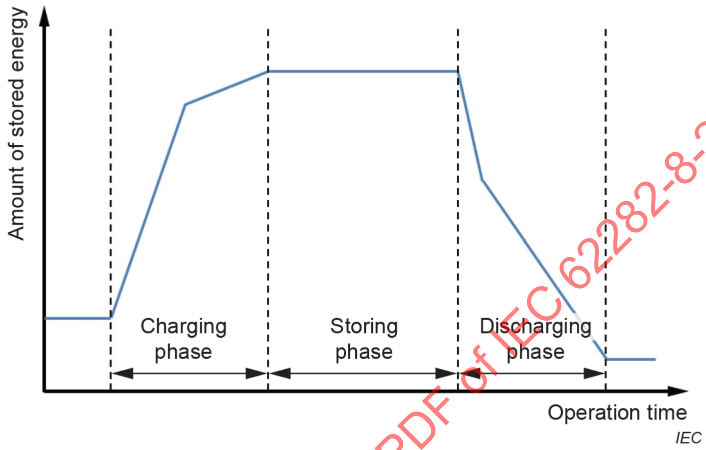


Figure 3 – Typical sequence of phases during the system operation

Table 2 – Required steps before executing the measurement

	Required steps	Actions
1	Note the system components' configuration.	
2	Define the system boundary.	Define ambient conditions.
3	Note the initial operating state of the system.	Report the operation history of the system.
4	Confirm the rated operating conditions and the limit operating conditions for the system.	Confirm the rated operating conditions and the limit operating conditions for the system between system manufacturer and customer.
5	Define the tests to be executed.	Consider the mutual interaction of the system components
6	Define the measurement methods and set up the instruments.	Check and report instrument uncertainty and permissible variation. Execute safety measures.
7	Execute the measurement.	

4.4 Environmental conditions

The reference environmental conditions shall be the normal environmental conditions as specified in IEC 62933-2-1.

Air temperature, relative humidity and pressure shall be measured as ambient conditions. Supplementary items shall be recorded, if needed. In the case of an outdoor installation, the information concerning hoarfrost, dew, hail, rain, snow, wind, and solar radiation shall be recorded.

When the EES system is intended to be used under conditions different from the reference environmental conditions, an agreement shall be established between the system manufacturer and the customer. In those cases, the appropriate ambient conditions for the test shall be agreed between the system manufacturer and the customer.

If required, the EES system may also be tested under the most extreme environmental conditions. In this case, the EES system manufacturer shall provide the most extreme environmental conditions.

4.5 Maximum permissible variation in test operating conditions

The tolerable variation of each operating parameter in the testing EES system shall fall within the following range:

– power: ±5 % relative to set point;

– ambient temperature: ±5 K;

– ambient relative humidity: ±10 %.

5 System parameters

5.1 General

The following parameters shall be specified as the common basic parameters to ensure capability and performance of an EES system using hydrogen:

- electric energy storage capacity;
- rated electric power input;
- rated net electric power output;
- roundtrip electrical efficiency.

In addition, the following parameters shall be specified if required:

- system response (step response time and ramp rate);
- minimum switchover time;
- stand-by state loss rate;
- thermal input and output;
- hydrogen input and output;
- acoustic noise level;
- total harmonic distortion;
- discharge water quality;
- electrolyser performance;
- hydrogen storage performance;
- fuel cell performance;
- water management system performance;
- battery performance;
- oxygen storage performance.

5.2 Electric energy storage capacity

Electric energy storage capacity is the electric energy that can be extracted from the EES system at the POC under reference environmental conditions as specified in 4.4. The electric energy storage capacity shall be evaluated considering energy losses. The electric energy storage capacity is the electric energy discharged from fully charged state to fully discharged state of the EES system, at rated output conditions.

The EES system may contain several types of energy source storages other than electricity and hydrogen, such as heat and oxygen. In those cases, each property of the components related to the energy source storages should be reported separately, adding to the electric energy storage capacity for the EES system.

5.3 Rated electric power input

The rated electric power input ($P_{\mathrm{el,in}}$) is the electric power that the tested EES system can absorb for a specified time at the POC under the reference environmental conditions specified in 4.4. The rated electric power input shall be specified together with applicable input duration. The rated electric power input and the applicable input duration, along with the conditions including input and output rates of heat, water flow, oxygen flow and air flow, shall be agreed by the system manufacturer and the customer.

In the case where more than one POC for electric power input is present in the EES system, rated electric power input is calculated from the total of the concurrent measurements of all electric power inputs at the POC. Typically, it contains the electric power inputs of the electrolyser or reversible cell, battery and other electrically operated components.

5.4 Rated net electric power output

The rated net electric power output ($P_{\mathrm{el,out}}$) is the net electric power that the tested EES system can provide for a specified time at the POC under the reference environmental conditions specified in 4.4. The rated net electric power output shall be specified together with applicable output duration. The rated net electric power output and the applicable output duration, along with the conditions including input and output rates of heat, water flow, oxygen flow and air flow, shall be agreed by the system manufacturer and the customer.

In the case where more than one electric POC is present in the EES system, rated net electric power output is calculated from the difference of the measured electric power outputs and inputs at all POCs. Typically, it contains the electric power connections of the fuel cell or the reversible cell and the battery.

5.5 Roundtrip electrical efficiency

The roundtrip electrical efficiency (η_{el}) is the ratio of net electric energy output ($W_{\mathrm{el,out}}$) during discharging to electric energy input ($W_{\mathrm{el,in}}$) during charging of the EES system for one charging–discharging cycle which has the same energy storage level at the start and at the end of the measurement.

NOTE Since the net electric energy output is considered during discharging, the electric energy input during this phase does not have to be added to the electric energy input during charging.

The boundary conditions of an electric input and output are defined. The test state is defined. The operating conditions for testing are determined. They include input and output rates of net electric power, heat, water flow, oxygen flow and air flow, and energy storage levels of electric energy and energy other than electricity. They shall be agreed by the system manufacturer and the customer. These items shall be reported with the measurement results.

The roundtrip electrical efficiency is measured over one charging–discharging cycle for specified energy storage levels using specified input and output rates of net electric power, heat, water flow, oxygen flow and air flow. At the end of the charging–discharging cycle, the level of charge and the operating conditions of the tested EES system shall be the same as those before the charging–discharging cycle.

For EES systems with an internal hydrogen storage, the charging–discharging cycle is defined by operation from the minimum to the maximum state of charge of the hydrogen storage and back to minimum state of charge. For EES systems without an internal hydrogen storage, the charging–discharging cycle is defined by comparing the mass of hydrogen which is delivered during charging operation and the mass of hydrogen which is supplied during discharging operation. The cycle is complete when the mass of the delivered hydrogen during charging equals the mass of the supplied hydrogen during discharging.

The roundtrip electrical efficiency can be affected by energy storage levels, electric power input and net output rates, electric energy consumption of the system operation, operating conditions for components relating to an energy source other than electricity, as well as the reference environmental conditions.

5.6 System response (step response time and ramp rate)

5.6.1 Step response time

The step response time of the EES system is the duration of the time interval between the instant t_0 when the EES system, which is in steady state, receives the set point and the instant t_3 when the electric power at the POC reaches the set point (within ±2 %) as shown in Figure 4. Detailed definition of t_0 shall be agreed between the system manufacturer and the customer. The reference set point for the definition of the step response time is the rated input or output power.

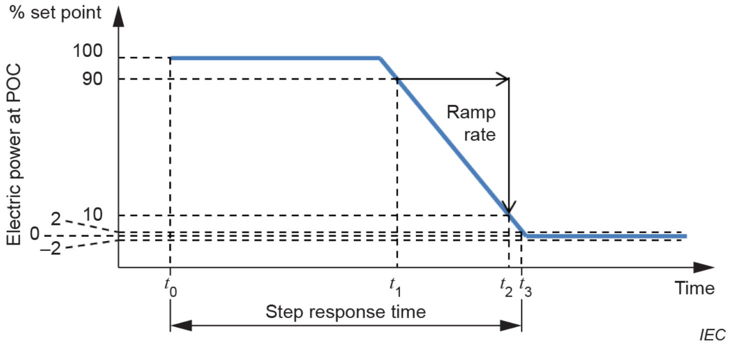
$$t_{sr} = t_3 - t_0 \tag{1}$$

where

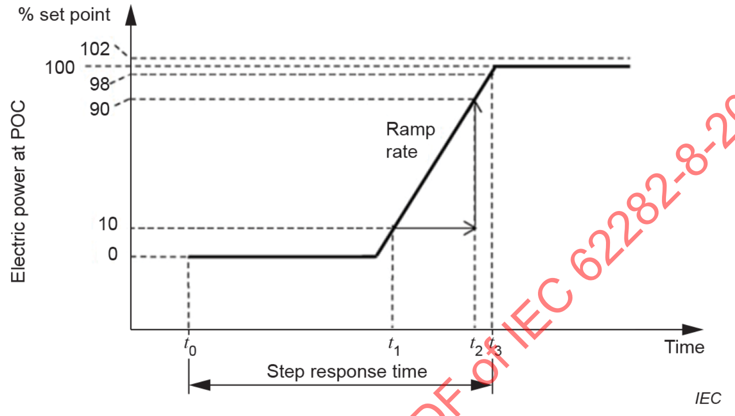
t_{sr} is the step response time (s);

t_0 is the time point when the EES system, which is in steady state, receives the set point value;

t_3 is the time point when the electric power at the POC reaches the set point (within ±2 %).



a) **Negative ramp rate**



b) **Positive ramp rate**

NOTE The ramp rate and the parameters t_1 and t_2 are explained in 5.6.2.

Figure 4 – Step response time and ramp rate of EES system

5.6.2 Ramp rate

The ramp rate of the EES system is the average rate of electric power variation per unit of time between t_2 and t_1 as shown in Figure 4 a) for negative ramp rate and Figure 4 b) for positive ramp rate. For the negative (positive) state, t_1 is the time point when the electric power at the POC becomes less than 90 % (higher than 10 %) of the set point value and t_2 is the time point when the electric power at the POC becomes less than 10 % (higher than 90 %) of the set point value. The reference set point for the definition of the ramp rate is the rated input and output power. In case of non-linear characteristic or transition behaviour during the mode change, for example charge–discharge–charge, the definition of ramp rate shall be agreed by the system manufacturer and the customer.

$$dP/dt = \frac{P_{el}(t_2) - P_{el}(t_1)}{t_2 - t_1} \quad (2)$$

where

dP/dt	is the ramp rate (W/s);
t_1	is the time point when the electric power at the POC becomes less than 90 % (negative ramp rate) or higher than 10 % (positive ramp rate) of the set point value;
t_2	is the time point when the electric power at the POC becomes less than 10 % (negative ramp rate) or higher than 90 % (positive ramp rate) of the set point value;

$P_{el}(t_1)$ is the electric power at the POC at time point t_1;

$P_{el}(t_2)$ is the electric power at the POC at time point t_2.

5.7 Minimum switchover time

The minimum switchover time is the minimum duration required to switch the operating conditions of the tested EES system from a specified charging phase to a specified discharging phase, or vice versa. It specifically comprises the time that is required to go from a specified charging or discharging phase to open circuit voltage (OCV) phase, purging of gas lines if applicable, setting of auxiliary components if applicable and to go to the opposite specified operating phase. The switchover times from charging to discharging phase and vice versa can be different, so both values shall be reported. The charging and discharging phases for the test (for example, 80 % of the nominal input and output power rates) shall be agreed between the system manufacturer and the customer.

5.8 Stand-by state loss rate

The stand-by state loss rate of the EES system is the sum of the energy loss rate and the energy consumption rate of the EES system during the stand-by state, which is typically the phase between the charge and the discharge operation. The measurement time of the stand-by state loss rate shall be chosen from among one hour, one day or one week or the time agreed upon by the system manufacturer and the customer. The energy consumption of any auxiliary operation within the system boundary shall be included.

NOTE Stand-by state energy losses include electric energy losses such as parasitic loads or supply of controls and gas losses.

5.9 Heat input

The heat input ($P_{th,in}$) is the thermal power, which is absorbed by the tested EES system during the system operation in the different operation phases (charging, storage, discharging). The heat input is fed to the EES system at the POC, using a heat transfer fluid (e.g. air, water, steam).

In the case where there is more than one POC for heat input, the heat input is calculated from the total of concurrent measurements of all heat inputs at the POC.

5.10 Hydrogen input and output rate

For systems connected to a hydrogen supply infrastructure, the hydrogen input rate ($q_{m,H2,in}$) and hydrogen output rate ($q_{m,H2,out}$) are the mass flow rate of hydrogen at the POC into and out of the tested EES system, respectively, during the different operation phases (charging, storage, discharging).

5.11 Recovered heat output

The recovered heat output ($P_{th,out}$) is the usable thermal power output, which is recovered by the tested EES system during the system operation in the different operation phases (charging, storage, discharging). The recovered heat output is dissipated at the POC, using a heat transfer fluid (typically water). The recovered heat output does not include waste heat losses, for example due to system components cooling.

5.12 Acoustic noise level

The acoustic noise level is the total acoustic noise level, including all noise sources of the EES system. It shall be measured under the rated operating states or those states which are agreed between the system manufacturer and the customer.

5.13 Total harmonic distortion

The total harmonic distortion is the overall harmonic distortion of the EES system. It shall be measured under the rated operating states or those states which are agreed between the system manufacturer and the customer.

5.14 Discharge water quality

All discharge water sources of the EES system are covered. The quality of the discharged water shall be measured under the rated operating states or those states which are agreed between the system manufacturer and the customer.

6 Test methods and procedures

6.1 General

System parameters specified in Clause 5 and component performances shall be reported selectively according to the purpose of the performance test.

The parameters listed in 5.2 to 5.5 are primary performance indicators of the EES system using hydrogen. They are measured under the rated test conditions or other operating conditions within the limit operating conditions. These conditions for testing shall be agreed between the system manufacturer and the customer.

The other parameters listed in Clause 5 are secondary performance indicators of the EES system. The testing conditions as specified in 4.4 shall be applied, based upon agreement between the system manufacturer and the customer.

Suitable performance test standards for electricity-converting devices and EES shall be followed as available.

6.2 Electric energy storage capacity test

Electric energy storage capacity shall be tested at rated input and output conditions under reference environmental conditions as specified in 4.4, and if required, at additional operating conditions different from the rated ones.

For EES systems with an internal hydrogen storage, which are connected to an external hydrogen supply, the hydrogen supply at the POC shall be closed during this test. The electric energy storage capacity can not be determined for EES systems without an internal hydrogen storage. Only in case of a limited and known state of charge of the external hydrogen supply infrastructure can the latter be considered like an internal hydrogen storage and the electric energy storage capacity be determined.

The electric energy storage capacity shall be evaluated as the electric energy discharged at the rated output conditions and the output duration time starting from the fully charged state of the system. Values of output power from the tested EES system shall be obtained at all POCs using a calibrated power meter or a calibrated combination of one or more voltmeters and amperemeters, as appropriate.

For the measurement of the electric power input, the test methods of ISO 22734:2019 for electrolysers, IEC 62282-3-200 for stationary fuel cells, IEC 62282-8-101 for reversible solid oxide electrolysis (SOE) cells and IEC 62282-8-102 for reversible polymer electrolyte membrane (PEM) cells shall apply. Furthermore, the guidelines of IEEE Std 1459™-2010 may be used.

The measurement shall be performed in the three consecutive steps a) to c). The electric energy storage capacity shall be calculated by Formula (3).

a) The tested EES system shall be discharged to the specified minimum electric energy storage level in accordance with the system specifications and operating instructions.
b) The tested EES system shall be charged to the specified maximum electric energy storage level at rated input conditions in accordance with the system specifications and operating instructions.
c) The tested EES system shall be discharged at the rated output conditions of the system in accordance with the system specifications and operating instructions. The EES system shall be discharged to the specified minimum electric energy storage level associated with the system specification and operation instructions. The net electric power output over time shall be measured and recorded.

Subsequently, the net electric energy output is calculated using Formula (3). The electric energy storage capacity (W_{el}) is defined as the net electric energy output during this test ($W_{\text{el,out}}$).

$$W_{\text{el}} = W_{\text{el,out}} = \sum_{i=1}^{n} P_{\text{el,out}}(t_i) \times \Delta t \qquad (3)$$

where:

W_{el}	is the electric energy storage capacity of the tested EES system (Wh);
$W_{\text{el,out}}$	is the calculated net electric energy output (Wh);
$P_{\text{el,out}}(t_i)$	is the net electric power output at time point t_i (W);
Δt	is the sampling time of measurement (h);
n	is the number of measurements until discharge completion.

The rated input and output operation conditions shall also be reported. If the energy storage capacities of components of the EES are reported separately, the following standards shall apply:

- hydrogen storage capacity of hydrogen tanks: performance test methods of the related parts in ISO 16111, ISO 19880-1, ISO 19881, and ISO 19882;
- electricity storage capacity of batteries and similar components: performance test methods of IEC 61427-1 and IEC 61427-2.

For components without suitable test standards for the evaluation of energy storage capacities, the applied test method and conditions shall be reported.

6.3 Rated electric power input test

The rated electric power input test of the EES system shall be conducted to confirm that constant rated electric power can be input to the system for a specified duration at the POC. This test shall be performed using the electric energy storage capacity measurement test routine in 6.2 as follows.

It shall be confirmed that the tested EES system can absorb, or be charged at, the set electric power for a specified duration at the POC. The rated electric power input of the system shall be applied as the set electric power value in this test.

In step b) of the electric energy storage capacity test in 6.2, the rated electric power is input to the tested EES system at the set electric power. The input electric power and the charging time shall be measured. The measured values of the input electric power and the charging time duration shall be compared to the specified parameters and reported. The duration for which this rated electric power is maintained shall be measured and reported. The rated input operating conditions shall also be reported.

For EES systems without an internal hydrogen storage, which are connected to a hydrogen supply infrastructure, the rated electric power input shall be determined by using step b) of 6.5.2.2 accordingly.

Where an EES system comprises more than one electrolyser, this test may also be conducted at a fraction of the rated electric power which corresponds to the non-concurrent operation of the electrolysers. This fraction may also correspond to the concurrent operation of more than one but not all electrolysers. The same applies to an EES system, which comprises more than one reversible cell. The specified duration at which the selected fraction of rated electric power can be input to the EES system at the POC shall be reduced proportionally. Alternatively, this duration shall be increased so that its value multiplied by the fraction of the rated electric power equals the product of the rated electric power and the original duration (rated electric energy input).

6.4 Rated net electric power output test

The rated net electric power output test of the EES system shall be conducted to confirm that constant rated net electric power can be output from the system for a specified duration at the POC. This test shall be performed using the electric energy storage capacity measurement test routine in 6.2 as follows.

It shall be confirmed that the tested EES system is able to output the set net electric power for a specified duration at the POC. The rated net electric power output of the system shall be applied as the set power value in this test.

In step c) of the electric energy storage capacity test in 6.2, the rated net electric power is output from the tested EES system at the set electric power. The net electric power output and the discharge time shall be measured and reported. The measured values of the net electric power output and the discharge time duration shall be compared to the specified parameters. The duration for which this rated electric power is maintained shall be measured and reported. The rated output conditions shall also be reported.

For EES systems without an internal hydrogen storage, which are connected to a hydrogen supply infrastructure, the rated electric power input shall be determined by using step a) of 6.5.2.2 accordingly.

Where an EES system comprises more than one fuel cell, this test may also be conducted at a fraction of the rated net electric power which corresponds to the non-concurrent operation of the fuel cells. This fraction may also correspond to the concurrent operation of more than one but not all fuel cells. The same applies to an EES system, which comprises more than one reversible cell. The specified duration at which the selected fraction of rated net electric power can be output from the EES system at the POC shall be reduced proportionally. Alternatively, this duration shall be increased so that its value multiplied by the fraction of the rated net electric power equals the product of the rated net electric power and the original duration (rated net electric energy output).

6.5 Roundtrip electrical efficiency test

6.5.1 General

The roundtrip electrical efficiency test shall be conducted to determine the amount of net electric energy output which the tested EES system can deliver, relative to the amount of electric energy input into the system during the preceding charge, under specified operating conditions and at the same reference environmental conditions. This test shall be performed using the electric energy capacity test routine presented in 6.2. The test shall be carried out at least twice.

6.5.2 Test procedure

6.5.2.1 For systems with internal hydrogen storage, not connected to an external hydrogen supply infrastructure

The net electric energy output $W_{\text{el,out}}$ shall be measured and calculated during the electric energy storage capacity test; see 6.2 c). The electric energy input $W_{\text{el,in}}$ shall be measured and calculated accordingly during the electric energy storage capacity test; see 6.2 b). The electric energy input shall be determined analogously to the net electric energy output, using Formula (3).

6.5.2.2 For systems without internal hydrogen storage, connected to an external hydrogen supply infrastructure

The net electric energy output $W_{\text{el,out}}$ and the electric energy input $W_{\text{el,in}}$ of the tested EES system and the hydrogen mass flow into and out of the tested EES system shall be measured at rated input and output conditions under reference environmental conditions as specified in 4.4 and, if required, at additional operating conditions different from the rated ones.

The values of the input and output power shall be obtained at the electricity POC, using a calibrated power meter or a calibrated combination of one or more voltmeters and amperemeters, as appropriate. The values of the hydrogen mass flow into and out of the tested EES system shall be obtained at the hydrogen POC, using a calibrated hydrogen mass flow meter.

For the measurement of the electric power input, the test methods of ISO 22734:2019 for electrolysers, IEC 62282-3-200 for stationary fuel cells, IEC 62282-8-101 for reversible solid oxide electrolysis (SOE) cells and IEC 62282-8-102 for reversible polymer electrolyte membrane (PEM) cells shall apply. Furthermore, the guidelines of IEEE Std 1459-2010 may be used.

The measurement shall be performed in the two consecutive steps a) and b).

a) The tested EES system shall be operated in discharging mode at rated output conditions (positive electric power output and hydrogen input) in accordance with the system specifications and operating instructions, for a specified duration.

b) The tested EES system shall be operated in charging mode at rated input conditions (positive electric power input and hydrogen output) in accordance with the system specifications and operating instructions, until the mass of delivered hydrogen equals the mass of hydrogen supplied to the system during step a).

The mass of hydrogen supplied to the system during step a) can be determined using Formula (4). The mass of hydrogen delivered by the system during step b) can be determined accordingly.

$$m_{\text{H2,in}} = \sum_{i=1}^{n} q_{m,\text{H2,in}}\left(t_i\right) \times \Delta t \tag{4}$$

where

$m_{\text{H2,in}}$	is the hydrogen mass supplied to the system at the POC (g);
$q_{m,\text{H2,in}}$	is the hydrogen mass flow into the system at the POC (g/s);
Δt	is the sampling time of measurement (s);
n	is the number of measurements until end of discharging operation.

The net electric energy output $W_{\text{el,out}}$ shall be measured and calculated during step a) and the electric energy input $W_{\text{el,in}}$ shall be measured and calculated during step b). The values shall be determined in the same way as the method in 6.2, using Formula (3).

6.5.3 Calculation of the roundtrip electrical efficiency

The roundtrip electrical efficiency shall be calculated according to Formula (5).

$$\eta_{\text{el}} = \frac{W_{\text{el,out}}}{W_{\text{el,in}}} \times 100\ \% \qquad (5)$$

where

η_{el}	is the roundtrip electrical efficiency (%);
$W_{\text{el,out}}$	is the net electric energy output (Wh);
$W_{\text{el,in}}$	is the electric energy input (Wh).

NOTE $W_{\text{el,out}}$ considers electric energy losses due to energy conversion and the use of electric energy for system operation.

The roundtrip electrical efficiency shall be reported as indicated in Table 3, for example. Where an additional test is performed beyond the minimum required two cycles, an additional row shall be added to Table 3. The average value shall be calculated from each measured value and the roundtrip electrical efficiency shall be reported based on the average value.

Table 3 – Example of document format of roundtrip electrical efficiency

Test	**Start state of EES system** [a] (%)	**Electric power input** (W)	**Electric energy input** (Wh)	**Charged state of EES system** (%)	**Electric power output** (W)	**Net electric energy output** (Wh)	**End state of EES system** [a] (%)	**Roundtrip electrical efficiency** (%)
Test 1	X	X	X	X	X	X	X	X
Test 2	X	X	X	X	X	X	X	X
Average	X	X	X	X	X	X	X	X

[a] Start and end (discharged) states have the same energy storage level for one charging–discharging cycle measurement. The values for start and end state are typically 0 %, the value for charged state is typically 100 %.

6.6 Other system performance tests

6.6.1 System response test, step response time and ramp rate

The system response is measured, after confirming that the system is operating under the test state. The performance evaluation test shall be conducted by following the applicable standards for the response of the EES system.

The following typical evaluation procedures refer to IEC 62933-2-1.

The procedures are listed below. The EES system shall absorb or provide the electric power according to the set point of rated input or output power. The set point and the input or output power at the POC shall be recorded with a data acquisition system at regular intervals of time, with appropriate time resolution.

The calculation of the step response times t_{sri} shall be carried out using Formula (1) in 5.6.1. The calculation of the ramp rates shall be carried out using Formula (2) in 5.6.2.

a) The EES system shall be charged or discharged to 50 % state of available energy or specified capacity value agreed upon between the system manufacturer and the customer.

b) The set point of electric power input or output shall be changed to zero. This set point shall be maintained until the electric power input or output is within ±2 % of the rated power input or output.

c) The set point of the electric power input shall be changed to rated power input. The set point value shall be maintained until the electric power input at the POC is within ±2 % of rated power input. Step response time and ramp rate of this step shall be reported as t_{sr1} and $\mathrm{d}P/\mathrm{d}t_1$, respectively.

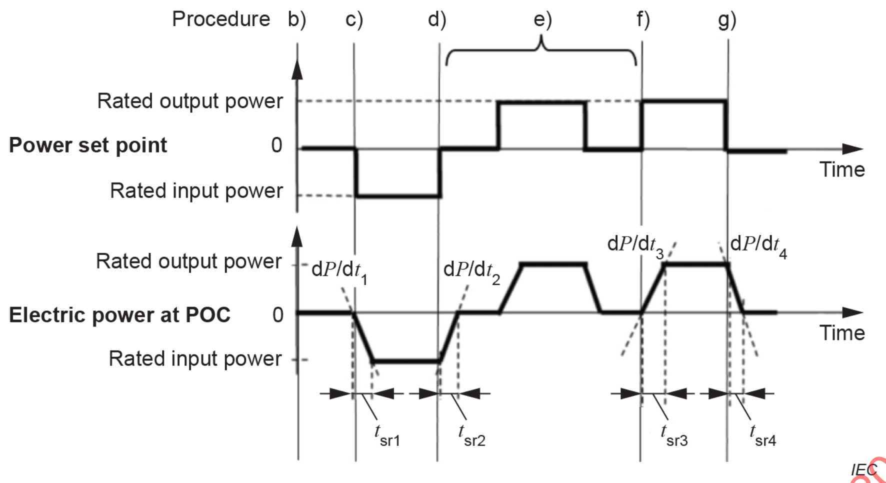
d) The set point of the electric power input shall be changed to zero. The set point value shall be maintained until the electric power input at the POC is ±2 % of rated power input. Step response time and ramp rate of this step shall be reported as t_{sr2} and $\mathrm{d}P/\mathrm{d}t_2$, respectively.

e) The EES system shall be discharged to 50 % state of available energy or specified capacity value agreed between the system manufacturer and user.

f) The set point of electric power output shall be changed to rated power output. The set point value shall be maintained until the electric power output at the POC is within ±2 % of rated power output. Step response time and ramp rate of this step shall be reported as t_{sr3} and $\mathrm{d}P/\mathrm{d}t_3$, respectively.

g) The set point of electric power output shall be changed to zero. The set point value shall be maintained until the electric power output at the POC is ±2 % of rated power output. Step response time and ramp rate of this step shall be reported as t_{sr4} and $\mathrm{d}P/\mathrm{d}t_4$, respectively.

Figure 5 shows the procedure listed from step b) to step g), step a) is omitted.



SOURCE IEC 62933-2-1:2017, Figure 7, modified.

Figure 5 – Step response test

6.6.2 Minimum switchover time test

The minimum switchover time is measured, after confirming that the system is operating under the test state. A typical test procedure for the switchover time of an EES system is listed below and shall apply (see Figure 6).

a) The specified charging and discharging power rates and the specified energy capacity levels for the test shall be agreed between the system manufacturer and the customer.

b) The tested EES system shall be charged or discharged to the specified capacity values.

c) The charging and discharging power rates at the POC shall be maintained until they are within ±2 % of their set points (see Figure 4).

d) Minimum switchover times from the charging phase to the discharging phase and from the discharging phase to charging phase shall be measured and reported.

Figure 6 explains the minimum switchover time from charging phase to discharging phase t_{so1} and from discharging phase to charging phase t_{so2}.

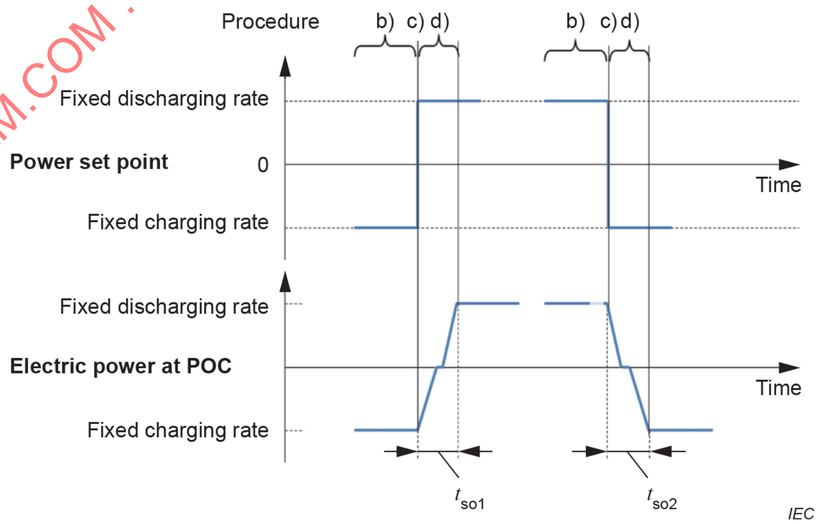


Figure 6 – Minimum switchover time test

6.6.3 Stand-by state loss rate test

The stand-by state loss rate is measured, after confirming that the system is operating under the test state. The typical test procedure for the stand-by loss rate of an EES system is listed below and shall apply.

NOTE 1 The tests are similar to the IEC 62933-2-1 self-discharge test for EES systems.

NOTE 2 This test is not intended to determine hydrogen leakages, for which the relevant methods are given in IEC 62282-2-100 (fuel cell modules) and IEC 62282-3-100 (stationary fuel cell power systems).

a) The EES system shall be charged or discharged to 100 % of the rated energy capacity or specified energy capacity value agreed between the system manufacturer and the customer.

b) The EES system shall be kept at a stand-by state for the measurement period of self-discharging. The measurement period of self-discharging shall be chosen from among one hour, one day or one week or the time agreed between the system manufacturer and the user.

c) The electric energy input to the EES system shall be measured at the POC throughout the measurement period of self-discharging.

d) After completing the measurement period of self-discharging, the EES system shall be charged to the initial energy capacity level, and the electric energy input shall be measured at the POC.

e) The self-discharge power consumption shall be evaluated by using the sum of electric energy input measured in step c) and step d) in accordance with Formula (6). The electric energy input for re-charging shall be determined analogously to the net electric energy output using Formula (3).

$$P_{\text{el,loss}} = \frac{W_{\text{el,in}}}{t_{\text{loss}}} \tag{6}$$

where

$P_{\text{el,loss}}$ is the stand-by state loss rate (W);

$W_{\text{el,in}}$ is the sum of electric energy inputs during self-discharging in step c) and re-charging in step d) (Wh);

t_{loss} is the measurement time of self-discharging (h).

6.6.4 Heat input test

This test only applies to EES systems being equipped with a POC for heat input, using a heat-transfer fluid.

The heat input test of the EES system shall be performed using the electrical energy storage capacity test in 6.2 and the stand-by loss rate test in 6.6.3. The heat input can be determined by using the measurement methods for external thermal input, as given in IEC 62282-3-200.

The heat input shall be determined separately and reported for the charging phase in accordance with 6.2 b), for the discharging phase in accordance with 6.2 c), and for the storage phase in accordance with 6.6.3. If during one of these phases no heat input occurs, the test of that phase can be omitted. The measured values of the heat input shall be compared to specified values, if available. The test operating conditions shall also be reported, comprising the temperature of the heat transfer fluid input and output, and the respective flow rate. If other suitable heat input test methods are applied, the test methods and conditions shall be reported.

6.6.5 Recovered heat output test

This test only applies to EES systems being equipped with a POC for recovered heat output, using a heat transfer fluid.

The recovered heat output test of the EES system shall be performed using the electrical energy storage capacity test in 6.2 and the stand-by loss rate test in 6.6.3. The recovered heat output can be determined by using the measurement methods for recovered thermal power output, as given in IEC 62282-3-200.

The recovered heat output shall be determined separately and reported for the charging phase in accordance with 6.2 b), for the discharging phase in accordance with 6.2 c), and for the storage phase in accordance with 6.6.3. If during one of these phases no recovered heat output occurs, this test can be omitted. The measured values of the recovered heat output shall be compared to the specified values. The test operating conditions shall also be reported, comprising the temperature levels of the heat fluid inlet and outlet and the heat fluid flow rate. If other suitable recovered heat output test methods are applied, the test methods and conditions shall be reported.

6.6.6 Hydrogen input and output rate test

This test only applies to EES systems being equipped with a POC for hydrogen input and output, which are connected to a hydrogen supply infrastructure.

The hydrogen input and output rate test of the EES system shall be performed by measuring the hydrogen mass flow into and out of the system, using the roundtrip electrical efficiency test routine in 6.5.2.2. The hydrogen input and output rate can be determined by using the measurement methods for fuel input, as given in IEC 62282-3-200.

The hydrogen input rate shall be determined for the charging phase by using the routine in 6.5.2.2 a). The hydrogen output rate shall be determined for the discharging phase by using the routine in 6.5.2.2 b). The measured values of the hydrogen input and output rate shall be compared to specified values, if available. The test operating conditions shall also be reported, comprising the temperature and the pressure of the hydrogen at the POC.

6.6.7 Acoustic noise level test

The acoustic noise level is measured, after confirming that the system is operating under the test state. This test shall be conducted in accordance with ISO 3746, ISO 9614-1 or ISO 11204 as appropriate.

6.6.8 Total harmonic distortion test

Total harmonic distortion shall be measured and reported for EES systems that are connected to an AC grid. IEC 61000-4-7 and IEC 61000-4-13 provide measurement guidance.

6.6.9 Discharge water quality test

Discharge water quality is measured, after confirming that the system is operating under the test state and intended water discharge takes place. Any appropriate methods for water quality evaluation, for example ISO 15839, ISO 17381 and IEC 62282-3-201, apply.

6.7 Component performance test

6.7.1 Electrolyser performance test

In addition to the tests specified in 6.6, the hydrogen production rate, the electric power and the water consumption are measured for the electrolyser or the reversible cell module in electrolysis mode. The boundary of the electrolyser or the reversible cell module in the tested EES system shall be agreed between the system manufacturer and the customer. The respective performance evaluation methods of ISO 22734:2019 for the hydrogen production rate and the electric power, IEC 62282-8-101 (solid oxide electrolysis cells) or IEC 62282-8-102 (polymer electrolyte membrane cells) for the electric power of single cell and stack, and IEC 62282-3-200 for the water consumption apply.

As an optional property evaluation test, the purge gas consumption is measured for the electrolyser or the reversible cell module in electrolysis mode. The respective performance evaluation method of IEC 62282-3-200 applies.

The measurements shall be conducted under the test state and under the rated operating conditions, using the referenced standards in Table 4.

For electrolysers without suitable performance evaluation test standards, the applied test method and conditions shall be recommended by the manufacturer and documented in the test report (see Clause 7).

Table 4 – Additional parameters measured on the electrolyser or the reversible cell module in electrolysis mode

Parameter	Definition	Reference
Hydrogen production rate	Electrolytic hydrogen production rate (kg/h)	ISO 22734:2019
Electric power	Electric power input (W)	ISO 22734:2019 IEC 62282-8-101 IEC 62282-8-102
Water consumption[a]	Water consumption rate (kg/h)	
Purge gas consumption	Amount of supplied inert or dilution gas (l/min)	IEC 62282-3-200

[a] Water consumption of the electrolyser for the electrolysis and others, if used (i.e. cooling water).

6.7.2 Hydrogen storage performance test

In addition to the tests specified in 6.6, the hydrogen storage rate, the operating power and the consumed electricity for storing the unit amount of hydrogen operated under the test state and the rated operating conditions are measured for the hydrogen storage components. Any appropriate methods for evaluating hydrogen storage performance shall apply in accordance with Table 5 depending on the storage types of hydrogen. ISO 16111 is referenced as a method for evaluating the hydrogen storage capacity.

For the hydrogen storage without suitable performance evaluation test standards, the applied test method and conditions shall be recommended by the manufacturer and documented in the test report (see Clause 7).

Table 5 – Additional parameters measured on the hydrogen storage component

Parameter	Definition	Reference
Storage rate	Rate of storing hydrogen (kg/h)	For storage capacity: ISO 16111
Operating power	Electric power required for operation (W/kg)	
Consumed electricity	Electricity for storing unit amount of hydrogen (Wh/kg)	

6.7.3 Fuel cell performance test

In addition to the tests specified in 6.6, the electric power, the thermal power, the electrical efficiency and the overall efficiency are measured for the fuel cell or the reversible cell module in fuel cell mode. The respective performance evaluation methods of IEC 62282-3-200 or IEC 62282-3-201 or of IEC 62282-8-101 or IEC 62282-8-102 apply.

As an optional property evaluation test, the purge gas consumption is measured for the fuel cell or the reversible cell module in fuel cell mode. The respective performance evaluation method of IEC 62282-3-200 applies.

The measurements shall be conducted under the test state and under the rated operating conditions, using the referenced standards in Table 6.

For the fuel cells without suitable performance evaluation test standards, the applied test method and conditions shall be recommended by the manufacturer and documented in the test report (see Clause 7).

Table 6 – Additional parameters measured on the fuel cell or the reversible cell module in fuel cell mode

Parameter	Definition	Reference
Electric power	Net electric power output (W)	IEC 62282-3-200 IEC 62282-3-201
Electrical efficiency	Ratio of electric power output and fuel power input (%)	
Thermal power	Recovered thermal power output (W)	IEC 62282-3-201
Overall efficiency	Ratio of all useful power outputs and fuel power input (%)	
Purge gas consumption	Amount of supplied inert or dilution gas (m^3/s)	IEC 62282-3-200

6.7.4 Water management system performance test

In addition to the tests specified in 6.6, the water input flow rate (l/min) and the electric power input (W) are measured for the water management system. Use appropriate methods for evaluating fluid flow in closed conduits, for example ISO 4064-1 and ISO 4064-2. For the devices without suitable performance evaluation test standards, the applied test method and conditions shall be reported and they shall be recommended by the system manufacturer.

As optional performance evaluation tests, the water storage capacity (m^3, l), and the water purification quality (e.g. conductivity in µS/cm) are measured. Use standards of fluid flow in closed conduits for measuring the water storage capacity, for example ISO 4064-1 and ISO 4064-2.

For the water management systems without suitable performance evaluation test standards, the applied test method and conditions shall be recommended by the manufacturer and documented in the test report (see Clause 7).

Use appropriate standards for the determination of water purification quality, for example ISO 7888 (determination of electrical conductivity). Information about the typical impurities that are expected to affect the components' properties considerably shall be provided by the system manufacturer. These properties change during operation, so attention is important.

6.7.5 Battery performance test

In addition to the tests specified in 6.6, the charging capacity is measured for the battery. Also, the electric power input, the electric power output and the charge–discharge efficiency operated under the test state and the rated operating conditions are measured.

The performance evaluation test standards for the relevant type of battery apply; for example, IEC 61427-1 and IEC 61427-2 particularly for renewable energy storage.

For batteries without suitable performance-evaluation test standards, the applied test method and conditions shall be recommended by the manufacturer and documented in the test report (see Clause 7).

6.7.6 Oxygen storage performance test

In addition to the tests specified in 6.6, the oxygen storage capacity, the oxygen storage rate, the operating power and the consumed electricity for storing the unit amount of oxygen operated under the test state and the rated operating conditions are measured for the oxygen storage component. The applied measuring method and conditions shall be recommended by the manufacturer and documented in the test report (see Clause 7).

7 Test reports

7.1 General

Test reports shall accurately, clearly and objectively present sufficient information to demonstrate that all the objectives of the tests have or have not been attained.

7.2 Report items

The report shall present at least the following information:

a) title of the report;

b) authors of the report;

c) date of the report;

d) standard number, test procedure number;

e) location of the test;

f) tested system data (see 7.3 for details);

g) test conditions (see 7.4 for details);

h) test data (see 7.5 for details).

7.3 Tested system data description

The tested EES system data shall include at least the following information:

a) product name and brand name of the system;
b) constitution of the system;
c) definition of the boundary for the tested EES system;
d) type of electrolyser or reversible cell;
e) type of fuel cell;
f) type of hydrogen storage (if included);
g) type of battery (if included);
h) type of oxygen storage (if included).

7.4 Test condition description

The test condition description shall include at least the following information:

a) name of person or persons conducting the test;
b) instruments, calibration record;
c) definition of the operating state;
d) test procedure;
e) data acquisition method.

7.5 Test data description

The test data shall include at least the following information:

a) title of the test or tests;
b) test operating conditions;
c) test results;
d) ambient conditions;
e) uncertainty evaluation (see 7.6 for details).

If system operation requires external energies, such as heating, cooling and the like, and such energies are not incorporated in the performance tests, the energies and their amounts shall be reported under b).

7.6 Uncertainty evaluation

Uncertainties of instruments shall be reported. If necessary, variation of measurements and measurement uncertainties calculated from the variation of measurements and uncertainties of instruments should be reported (see ISO/IEC Guide 98-3).

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IEC 61000-4-7, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

IEC 61000-4-13, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*

IEC 61960-3, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for portable applications – Part 3: Prismatic and cylindrical lithium secondary cells and batteries made from them*

IEC 61987-1, *Industrial-process measurement and control – Data structures and elements in process equipment catalogues – Part 1: Measuring equipment with analogue and digital output*

IEC 62282-2, *Fuel cell technologies – Part 2: Fuel cell modules*[3]

IEC 62282-2-100, *Fuel cell technologies – Part 2-100: Fuel cell modules – Safety*

IEC 62282-3-100, *Fuel cell technologies – Part 3-100: Stationary fuel cell power systems – Safety*

IEC 62282-3-300, *Fuel cell technologies – Part 3-300: Stationary fuel cell power systems – Installation*

IEC TS 62749, *Assessment of power quality – Characteristics of electricity supplied by public networks*

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

IEC TS 62933-3-1, *Electrical energy storage (EES) systems – Part 3-1: Planning and performance assessment of electrical energy storage systems – General specification*

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

3 Withdrawn.

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

IEC 62984-2:2020, *High-temperature secondary batteries – Part 2: Safety requirements and tests*

ISO/IEC Guide 98-1, *Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement*

ISO/IEC Guide 98-3-SP1, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995) – Supplement 1: Propagation of distributions using a Monte Carlo method*

ISO 4064-1, *Water meters for cold potable water and hot water – Part 1: Metrological and technical requirements*

ISO 4064-2, *Water meters for cold potable water and hot water – Part 2: Test methods*

ISO 7888, *Water quality – Determination of electrical conductivity*

ISO 15839, *Water quality – On-line sensors/analysing equipment for water – Specifications and performance tests*

ISO/TR 15916, *Basic considerations for the safety of hydrogen systems*

ISO 17381, *Water quality – Selection and application of ready-to-use test kit methods in water analysis*

ISO 22538-1, *Space systems – Oxygen safety – Part 1: Design of oxygen systems and components*

ISO 22538-4, *Space systems – Oxygen safety – Part 4: Hazards analyses for oxygen systems and components*

ISO 26142, *Hydrogen detection apparatus – Stationary applications*

IEEE Std 1459-2010, *IEEE Standard Definitions for the Measurement of Electric Power Quantities Under Sinusoidal, Nonsinusoidal, Balanced, or Unbalanced Conditions*

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SOMMAIRE

COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

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TECHNOLOGIES DES PILES À COMBUSTIBLE –

Partie 8-201: Systèmes de stockage de l'énergie à partir de modules de piles à combustible réversibles – Procédures d'essai pour la performance des systèmes de conversion électrochimiques électriques à électriques

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L'IEC 62282-8-201 a été établie par le comité d'études 105 de l'IEC: Technologies des piles à combustible. Il s'agit d'une Norme internationale.

Cette deuxième édition annule et remplace la première édition parue en 2020. Cette édition constitue une révision technique.

Cette édition inclut les modifications techniques majeures suivantes par rapport à l'édition précédente:

a) prise en compte des systèmes raccordés à une infrastructure d'alimentation en hydrogène (réseaux d'hydrogène, cuves, cavernes ou canalisations);
b) ajout des débits d'hydrogène d'entrée et de sortie dans les paramètres du système (5.10);
c) révision de l'essai de capacité de stockage de l'énergie électrique (6.2);
d) révision de l'essai de rendement électrique aller-retour (6.5);
e) ajout de l'essai des débits d'hydrogène d'entrée et de sortie (6.6.6).

Le texte de cette Norme internationale est issu des documents suivants:

Projet	Rapport de vote
105/1034/FDIS	105/1050/RVD

Le rapport de vote indiqué dans le tableau ci-dessus donne toute information sur le vote ayant abouti à son approbation.

La langue employée pour l'élaboration de cette Norme internationale est l'anglais.

Ce document a été rédigé selon les Directives ISO/IEC, Partie 2, il a été développé selon les Directives ISO/IEC, Partie 1 et les Directives ISO/IEC, Supplément IEC, disponibles sous www.iec.ch/members_experts/refdocs. Les principaux types de documents développés par l'IEC sont décrits plus en détail sous www.iec.ch/publications.

Une liste de toutes les parties de la série IEC 62282, publiée sous le titre général *Technologies des piles à combustible*, se trouve sur le site Web de l'IEC.

Le comité a décidé que le contenu de ce document ne sera pas modifié avant la date de stabilité indiquée sur le site Web de l'IEC sous webstore.iec.ch dans les données relatives au document recherché. À cette date, le document sera

- reconduit,
- supprimé, ou
- révisé.

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INTRODUCTION

La présente partie de l'IEC 62282 spécifie les méthodes d'évaluation des performances des systèmes de stockage de l'énergie électrique utilisant de l'hydrogène et recourant à des réactions électrochimiques tant pour l'électrolyse de l'eau et de la vapeur que pour la production d'électricité.

NOTE La production de chaleur peut être un objectif secondaire.

Le présent document est destiné aux systèmes de conversion électrochimiques électriques à électriques, qui emploient généralement un ensemble électrolyseur-pile à combustible ou une cellule réversible pour les dispositifs de charge et de décharge électrique.

La classe de stockage de l'énergie électrique à haute intensité énergétique constitue une application cible type des systèmes de stockage de l'énergie électrique utilisant de l'hydrogène. Ces systèmes sont reconnus comme étant extrêmement utiles pour le stockage de l'énergie électrique sur une durée relativement longue, tel que le stockage efficace et la fourniture d'énergie électrique issue des énergies renouvelables et la stabilisation du réseau.

La série IEC 62282-8 vise à développer des méthodes d'essai des performances pour les systèmes de stockage de l'énergie et les systèmes tampons reposant sur des modules électrochimiques (qui combinent des piles à combustible et des cellules d'électrolyse, en particulier des cellules réversibles), en tenant compte des options de ré-électrification et de production de substance (et de chaleur) pour l'intégration durable des sources d'énergies renouvelables.

L'IEC 62282-8 comprend les parties suivantes, présentées sous le titre général Systèmes de stockage de l'énergie à partir de modules de piles à combustible réversibles:

- IEC 62282-8-101: Procédures d'essai pour la performance des cellules élémentaires et des piles à oxyde solide, comprenant le fonctionnement réversible
- IEC 62282-8-102: Procédures d'essai pour la performance des cellules élémentaires et des piles à membrane échangeuse de protons, comprenant le fonctionnement réversible
- IEC 62282-8-103[1]: Alkaline single cell and stack performance including reversible operation (disponible en anglais seulement)
- IEC 62282-8-201: Procédures d'essai pour la performance des systèmes électriques à électriques
- IEC 62282-8-202[2]: Power-to-power systems – Safety (disponible en anglais seulement)
- IEC 62282-8-301: Systèmes de conversion de l'énergie en méthane à base de piles à oxyde solide, comprenant le fonctionnement réversible – Méthodes d'essai des performances

L'IEC 62282-8-101, l'IEC 62282-8-102 et l'IEC 62282-8-201 ont été initiées conjointement et en premier lieu car elles constituent une priorité dictée par les besoins émergents des industries et les possibilités de développement technique. Ces parties sont présentées collectivement afin de souligner la nécessité d'une approche intégrée concernant l'application du système (c'est-à-dire une solution pour le stockage de l'énergie) et ses composants fondamentaux (c'est-à-dire les piles à combustible réversibles ou fonctionnant par inversion).

1 Futur projet.

2 Futur projet.

TECHNOLOGIES DES PILES À COMBUSTIBLE –

Partie 8-201: Systèmes de stockage de l'énergie à partir de modules de piles à combustible réversibles – Procédures d'essai pour la performance des systèmes de conversion électrochimiques électriques à électriques

1 Domaine d'application

La présente partie de l'IEC 62282 définit les méthodes d'évaluation des performances types des systèmes de stockage de l'énergie électrique utilisant de l'hydrogène. Elle s'applique aux systèmes qui emploient des dispositifs à réaction électrochimique à la fois pour la charge électrique et la décharge électrique. Le présent document s'applique aux systèmes conçus et utilisés pour l'entretien et le fonctionnement à des endroits fixes (en intérieur et à l'extérieur).

Les configurations conceptuelles des systèmes de stockage de l'énergie électrique utilisant de l'hydrogène sont représentées à la Figure 1 et la Figure 2.

La Figure 1 représente le système indépendamment équipé d'un module à électrolyseur et d'un module de pile à combustible. La Figure 2 représente le système équipé d'un module à cellule réversible.

Les composants indispensables sont un module à électrolyseur et un module de pile à combustible, ou un module à cellule réversible, un système de gestion global (comprenant une interface de données et pouvant inclure une gestion de la pression), un système de gestion thermique (pouvant inclure un stockage thermique), un système de gestion de l'eau (pouvant inclure un stockage de l'eau) et une alimentation en gaz de purge (gaz inerte, dans la pratique ni oxydant ni réducteur).

NOTE 1 Les composants indispensables sont indiqués en traits gras sur la Figure 1 et la Figure 2.

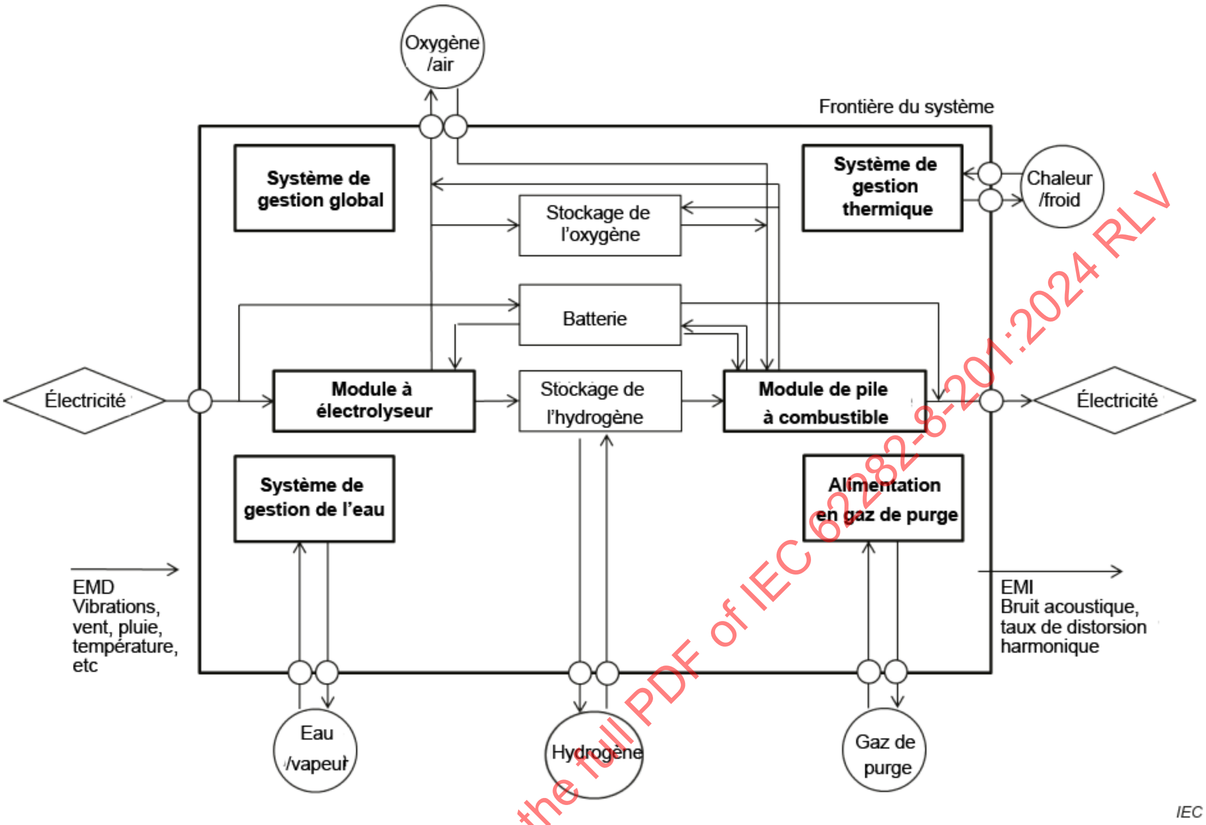
Le système peut être équipé soit d'un stockage de l'hydrogène, soit d'un raccordement à une infrastructure externe d'alimentation en hydrogène, soit d'une combinaison des deux. Les composants facultatifs peuvent être une batterie et un stockage de l'oxygène.

Le module à électrolyseur peut comprendre un ou plusieurs électrolyseurs du même type ou de type différent. Selon les conditions de fonctionnement et compte tenu de l'historique de fonctionnement, le système de gestion global peut commander le fonctionnement simultané des électrolyseurs. Le module de pile à combustible peut comprendre une ou plusieurs piles à combustible du même type ou de type différent. Selon les conditions de fonctionnement et compte tenu de l'historique de fonctionnement, le système de gestion global peut commander le fonctionnement simultané des piles à combustible. Le module à cellule réversible peut comprendre une ou plusieurs cellules réversibles de même type ou de type différent. Le module de pile à combustible peut comprendre une ou plusieurs piles à combustible du même type ou de type différent. Selon les conditions de fonctionnement et compte tenu de l'historique de fonctionnement, le système de gestion global peut commander le fonctionnement simultané des cellules réversibles.

La mesure des performances s'effectue dans la zone définie par le trait plein épais extérieur (frontière du système).

NOTE 2 Dans le contexte du présent document, le terme "réversible" n'a pas la signification thermodynamique d'un processus idéal. Le terme "réversible" est couramment employé dans le secteur des piles à combustible pour désigner le fonctionnement d'une cellule qui alterne entre le mode pile à combustible et le mode électrolyse.

Le présent document est destiné à être utilisé pour les échanges de données dans le cadre des transactions commerciales entre le fabricant du système et le client. Les utilisateurs du présent document peuvent choisir d'exécuter les éléments d'essai répondant à leurs besoins parmi ceux spécifiés dans le présent document.



Légende

EMD perturbation électromagnétique

EMI brouillage électromagnétique

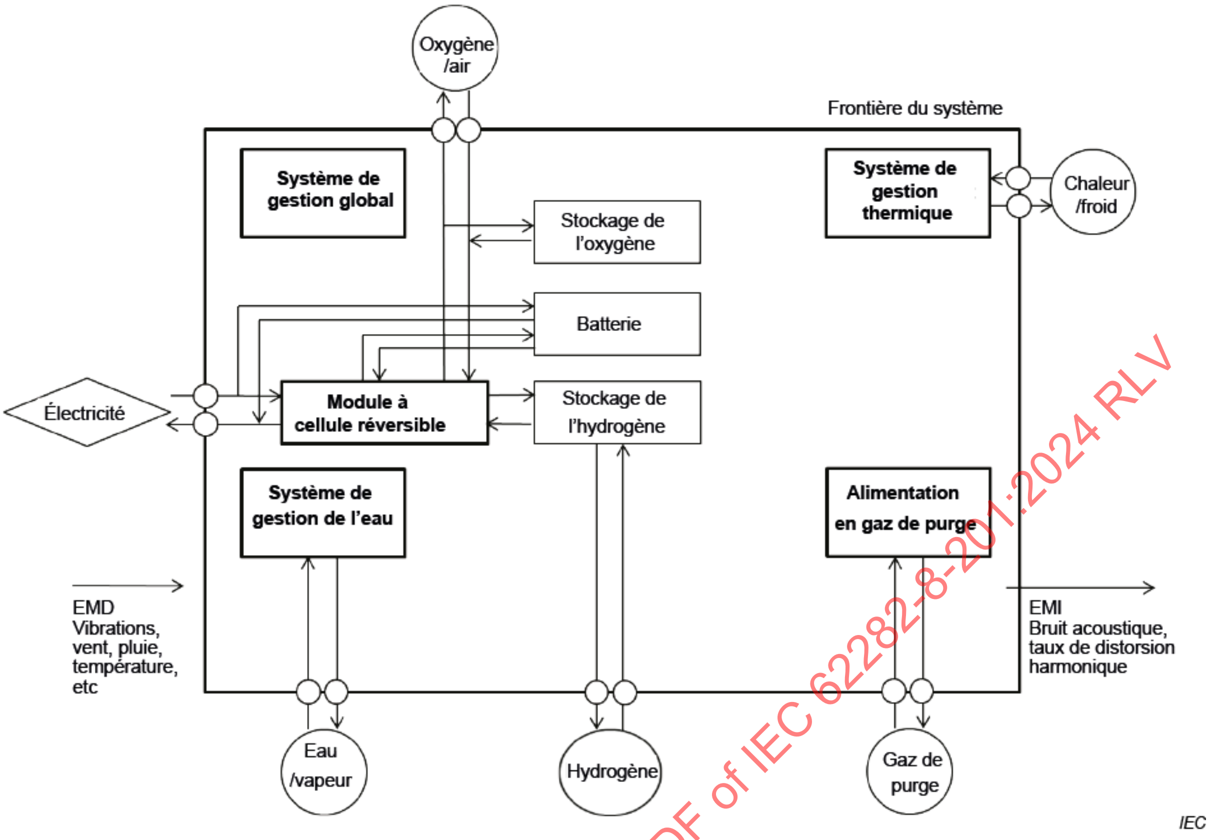
NOTE 1 Le système de gestion global, le système de gestion thermique, le système de gestion de l'eau et l'alimentation en gaz de purge peuvent avoir une relation avec l'électrolyseur, la pile à combustible, la batterie, le stockage de l'hydrogène et le stockage de l'oxygène, et peuvent également avoir des relations mutuelles.

NOTE 2 D'autres entrées ou sorties de fluide ou d'énergie, selon les types d'électrolyseur et de pile à combustible utilisés, peuvent être envisagées.

NOTE 3 L'entrée ou la sortie d'électricité peut être du courant continu et/ou du courant alternatif. Des sous-systèmes de conditionnement de l'énergie sont généralement utilisés.

NOTE 4 Il peut y avoir plusieurs points de connexion d'électricité pour l'entrée et/ou la sortie.

Figure 1 – Configuration d'un système de stockage de l'énergie électrique utilisant de l'hydrogène – Type de système avec électrolyseur et pile à combustible



Légende

EMD perturbation électromagnétique

EMI brouillage électromagnétique

NOTE 1 Le système de gestion global, le système de gestion thermique, le système de gestion de l'eau et l'alimentation en gaz de purge peuvent avoir une relation avec la cellule réversible, la batterie, le stockage de l'hydrogène et le stockage de l'oxygène, et peuvent également avoir des relations mutuelles.

NOTE 2 D'autres entrées ou sorties de fluide ou d'énergie, selon les types d'électrolyseur et de pile à combustible utilisés, peuvent être envisagées.

NOTE 3 L'entrée ou la sortie d'électricité peut être du courant continu et/ou du courant alternatif. Des sous-systèmes de conditionnement de l'énergie sont généralement utilisés.

NOTE 4 Il peut y avoir plusieurs points de connexion d'électricité pour l'entrée et/ou la sortie.

Figure 2 – Configuration d'un système de stockage de l'énergie électrique utilisant de l'hydrogène – Type de système avec cellule réversible

2 Références normatives

Les documents suivants sont cités dans le texte de sorte qu'ils constituent, pour tout ou partie de leur contenu, des exigences du présent document. Pour les références datées, seule l'édition citée s'applique. Pour les références non datées, la dernière édition du document de référence s'applique (y compris les éventuels amendements).

IEC 61427-1, *Accumulateurs pour le stockage de l'énergie renouvelable – Exigences générales et méthodes d'essais – Partie 1: Applications photovoltaïques hors réseaux*

IEC 61427-2, *Accumulateurs pour le stockage de l'énergie renouvelable – Exigences générales et méthodes d'essais – Partie 2: Applications en réseau*

IEC 62282-3-200, *Technologies des piles à combustible – Partie 3-200: Systèmes à piles à combustible stationnaires – Méthodes d'essai des performances*

IEC 62282-3-201, *Technologies des piles à combustible – Partie 3-201: Systèmes à piles à combustible stationnaires – Méthodes d'essai des performances pour petits systèmes à piles à combustible*

IEC 62282-8-101, *Technologies des piles à combustible – Partie 8-101: Système de stockage de l'énergie utilisant des modules à piles à combustible en mode inversé – Procédures d'essai pour la performance des cellules élémentaires et des piles à oxyde solide, comprenant le fonctionnement réversible*

IEC 62282-8-102, *Technologies des piles à combustible – Partie 8-102: Systèmes de stockage de l'énergie utilisant des modules à piles à combustible en mode inversé – Procédures d'essai pour la performance des cellules élémentaires et des piles à membrane échangeuse de protons, comprenant le fonctionnement réversible*

IEC 62933-2-1:2017, *Systèmes de stockage de l'énergie électrique (EES) – Partie 2-1: Paramètres unitaires et méthodes d'essai – Spécifications générales*

ISO/IEC Guide 98-3, *Incertitude de mesure – Partie 3: Guide pour l'expression de l'incertitude de mesure (GUM:1995)*

ISO 3746, *Acoustique – Détermination des niveaux de puissance acoustique et des niveaux d'énergie acoustique émis par les sources de bruit à partir de la pression acoustique – Méthode de contrôle employant une surface de mesure enveloppante au-dessus d'un plan réfléchissant*

ISO 9614-1, *Acoustique – Détermination par intensimétrie des niveaux de puissance acoustique émis par les sources de bruit – Partie 1: Mesurages par points*

ISO 11204, *Acoustique – Bruit émis par les machines et équipements – Détermination des niveaux de pression acoustique d'émission au poste de travail et en d'autres positions spécifiées en appliquant des corrections d'environnement exactes*

ISO 16111, *Appareils de stockage de gaz transportables – Hydrogène absorbé dans un hydrure métallique réversible*

ISO 19880-1, *Carburant d'hydrogène gazeux – Stations-service – Partie 1: Exigences générales*

ISO 19881, *Hydrogène gazeux – Réservoirs de carburant pour véhicules terrestres*

ISO 19882, *Hydrogène gazeux – Dispositifs limiteurs de pression thermiquement activés pour les conteneurs de carburant de véhicules à hydrogène comprimé*

ISO 22734:2019, *Générateurs d'hydrogène utilisant le procédé de l'électrolyse de l'eau – Applications industrielles, commerciales et résidentielles*

3 Termes, définitions et symboles

3.1 Termes et définitions

Pour les besoins du présent document, les termes et définitions suivants s'appliquent.

L'ISO et l'IEC tiennent à jour des bases de données terminologiques destinées à être utilisées en normalisation, consultables aux adresses suivantes:

- IEC Electropedia: disponible à l'adresse https://www.electropedia.org/
- ISO Online browsing platform: disponible à l'adresse https://www.iso.org/obp

3.1.1
stockage de l'énergie électrique
EES
installation capable de stocker de l'énergie électrique ou qui la convertit en une autre forme d'énergie et inversement, tout en la stockant

Note 1 à l'article: L'abréviation "EES" est dérivée du terme anglais développé correspondant "electric energy storage".

3.1.2
système de stockage de l'énergie électrique
système EES
installation avec des limites électriques définies, comportant au moins un EES, dont le but est d'extraire l'énergie électrique d'un réseau d'énergie électrique, de stocker cette énergie d'une certaine manière et d'injecter l'énergie électrique dans un réseau d'énergie électrique, et qui inclut des équipements de génie civil, de conversion de l'énergie ainsi que des équipements auxiliaires associés

Note 1 à l'article: Le système EES est commandé et coordonné dans le but de fournir des services aux opérateurs de réseaux d'énergie électrique ou aux utilisateurs de ces réseaux.

Note 2 à l'article: Dans certains cas, un système EES peut nécessiter une source d'énergie supplémentaire durant sa décharge, fournissant plus d'énergie au réseau d'énergie électrique que l'énergie emmagasinée.

[SOURCE: IEC 62933-1:2018, 3.2, modifié – Dans la définition, "connectée au réseau" et "en interne" ont été supprimés et, dans la version anglaise, "which extracts" a été remplacé par "whose purpose is to extract". La Note 2 à l'article a été raccourcie et la Note 3 à l'article a été supprimée.]

3.1.3
système EES utilisant de l'hydrogène
système EES comportant au moins un EES utilisant de l'hydrogène, dont le but est d'extraire de l'énergie électrique d'un réseau d'énergie électrique, de stocker cette énergie sous forme d'hydrogène et d'injecter l'énergie électrique dans un réseau d'énergie électrique, en utilisant l'hydrogène comme combustible

Note 1 à l'article: L'Article 1 fait référence aux configurations conceptuelles du système EES utilisant de l'hydrogène.

3.1.4
batterie
dispositif EES destiné à stocker de l'électricité par voie électrochimique et intégrant des fonctions de charge et de décharge de l'électricité

Note 1 à l'article: Les batteries permettent normalement d'absorber les fluctuations à court terme de l'électricité fournie, combinées au stockage de l'hydrogène d'un système EES utilisant de l'hydrogène.

3.1.5
électrolyseur
dispositif électrochimique qui convertit de l'eau ou de la vapeur en hydrogène et en oxygène par une réaction d'électrolyse

Note 1 à l'article: Les électrolyseurs comprennent les dispositifs d'électrolyse alcaline de l'eau, les dispositifs d'électrolyse de l'eau à membrane échangeuse de protons, les dispositifs d'électrolyse à cellule élémentaire à oxyde solide et d'autres dispositifs de type analogue.

3.1.6
environnement
milieu comportant un système EES utilisant de l'hydrogène, et incluant l'air, l'eau, la terre, les ressources naturelles, la flore, la faune, les êtres humains et leur interrelation

3.1.7
pile à combustible
dispositif électrochimique qui convertit l'énergie chimique d'un combustible et d'un oxydant en énergie électrique (courant continu), en chaleur et en produits de réaction

Note 1 à l'article: Le combustible et l'oxydant sont normalement stockés en dehors de la pile à combustible et transférés dans la pile à combustible lorsqu'ils sont consommés.

[SOURCE: IEC 60050-485:2020, 485-08-01 – modifié]

3.1.8
système de gestion thermique
sous-système du système EES utilisant de l'hydrogène, destiné à contrôler le stockage thermique et les écoulements de fluide thermique dans le système et ses POC (le cas échéant)

Note 1 à l'article: La chaleur est généralement utilisée entre les divers équipements du système. Le transfert de la chaleur de la pile à combustible par réaction exothermique vers une cellule d'électrolyse, en particulier une cellule d'électrolyse à oxyde solide pour la consommation endothermique, est un exemple d'utilisation mutuelle de la chaleur.

3.1.9
stockage de l'hydrogène
composant du système EES utilisant de l'hydrogène, destiné à stocker l'hydrogène produit par électrolyse de l'eau ou de la vapeur dans le système ou fourni à celui-ci

Note 1 à l'article: Il existe plusieurs types d'équipements de stockage de l'hydrogène qui varient en fonction des principes de stockage de ce gaz. Ils comprennent les gaz à haute et basse pression, les liquides, les alliages absorbeurs d'hydrogène (hydrogène absorbé dans un hydrure métallique réversible), les hydrures non métalliques, etc.

3.1.10
infrastructure d'alimentation en hydrogène
ensemble des dispositifs de transport et de stockage de l'hydrogène qui fournissent des points de connexion à des appareils à hydrogène, ces dispositifs fournissant de l'hydrogène aux appareils ou absorbant l'hydrogène délivré par ces derniers

3.1.11
conditions de fonctionnement limites
conditions à ne pas dépasser pour que le système EES fonctionne de façon normale et en toute sécurité

Note 1 à l'article: Elles sont recommandées par le fabricant du système EES compte tenu des caractéristiques de ce système.

3.1.12
énergie électrique nette de sortie
énergie électrique utilisable produite par le système EES utilisant de l'hydrogène, pouvant satisfaire aux besoins de l'utilisateur, à l'exclusion de la dissipation d'énergie électrique interne et externe du système

Note 1 à l'article: La dissipation d'énergie électrique interne et externe du système EES correspond généralement aux pertes d'énergie électrique dues aux manœuvres et aux connexions des équipements.

Note 2 à l'article: L'énergie électrique nette de sortie correspond à la différence entre les énergies électriques de sortie et les énergies électriques d'entrée à tous les POC.

3.1.13
puissance électrique nette
puissance de sortie du système ESS, disponible pour une utilisation externe

Note 1 à l'article: La puissance électrique nette de sortie correspond à la différence entre les puissances électriques de sortie et les puissances électriques d'entrée à tous les POC.

3.1.14
conditions de fonctionnement
conditions dans lesquelles fonctionne le système soumis à l'essai, plus spécifiquement chaque équipement du système EES soumis à l'essai, et incluant les conditions physiques telles que la plage des températures ambiantes, la pression, les niveaux de rayonnement, l'humidité et l'atmosphère

3.1.15
état de fonctionnement
état auquel le système soumis à l'essai, plus spécifiquement chaque équipement du système EES soumis à l'essai, fonctionne dans les conditions spécifiées

3.1.16
système de gestion global
sous-système du système EES utilisant de l'hydrogène, qui permet la surveillance et la commande de ce système, comprenant tous les équipements et l'exécution de toutes les fonctions d'acquisition, de traitement, de transmission et d'affichage des informations de processus nécessaires

Note 1 à l'article: Le système de gestion global inclut également un sous-système comprenant une disposition du matériel, des logiciels et du support de propagation permettant d'assurer le transfert de messages d'un composant ou sous-système du système EES utilisant de l'hydrogène à un autre, en incluant l'interface de données à liaisons externes.

Note 2 à l'article: En général, le sous-système de commande peut être connecté au POC primaire (simplement pour l'échange de données) et peut comprendre le sous-système de communication et le sous-système de protection.

Note 3 à l'article: Le sous-système de protection inclut un ou plusieurs équipements de protection, un ou plusieurs transformateurs d'instrument, des transducteurs, des câblages, un ou plusieurs circuits de déclenchement, une ou plusieurs alimentations auxiliaires. Selon le ou les principes du système de protection, le sous-système de protection peut inclure une ou toutes les extrémités de la section protégée et, éventuellement, un dispositif automatique de réenclenchement.

3.1.17
stockage de l'oxygène
composant du système EES utilisant de l'hydrogène, destiné à stocker l'oxygène produit par électrolyse de l'eau ou de la vapeur dans le système EES ou fourni à celui-ci

Note 1 à l'article: Le stockage de l'oxygène comporte des équipements, si nécessaire.

3.1.18
point de connexion
POC
point auquel un système EES utilisant de l'hydrogène est raccordé à une source d'alimentation ou d'extraction extérieure au système

Note 1 à l'article: En général, les POC sont des points de connexion d'électricité, de chaleur, d'eau, d'hydrogène, d'oxygène et d'air. La Figure 1 et la Figure 2 les présentent sous forme de cercles blancs situés à la frontière du système EES (carré à trait épais).

Note 2 à l'article: L'abréviation "POC" est dérivée du terme anglais développé correspondant "Point Of Connection".

3.1.19
état de veille
état de fonctionnement du système EES dans lequel le système ESS est chargé en tout ou partie, aucune charge ou décharge intentionnelle de l'énergie stockée ne se produisant par ailleurs, sauf l'autodécharge

3.1.20
conditions de fonctionnement assignées
conditions appliquées pour un fonctionnement normal des équipements ou des systèmes

Note 1 à l'article: Les conditions de fonctionnement assignées sont recommandées par les fabricants des équipements ou du système EES compte tenu des caractéristiques de ces équipements ou de ce système EES.

3.1.21
conditions d'entrée assignées
conditions spécifiées par le fabricant, auxquelles le système EES soumis à l'essai absorbe la puissance électrique d'entrée au POC

Note 1 à l'article: Les conditions d'entrée assignées comprennent les taux relatifs à la puissance électrique nette, à la chaleur, au débit d'eau, au débit d'oxygène et au débit d'air.

3.1.22
conditions de sortie assignées
conditions spécifiées par le fabricant, auxquelles le système EES soumis à l'essai fournit la puissance électrique de sortie au POC

Note 1 à l'article: Les conditions de sortie assignées comprennent les taux relatifs à la puissance électrique nette, à la chaleur, au débit d'eau, au débit d'oxygène et au débit d'air.

3.1.23
conditions d'essai assignées
conditions de fonctionnement limites spécifiques au système EES soumis à l'essai

Note 1 à l'article: Les conditions d'essai assignées sont convenues entre le fabricant du système EES et le client.

3.1.24
cellule réversible
dispositif électrochimique capable de fonctionner comme une pile à combustible ou bien comme un électrolyseur

Note 1 à l'article: Dans ce contexte, le terme "réversible" ne fait pas référence au principe thermodynamique d'un processus idéal.

3.1.25
rendement électrique aller-retour
énergie électrique déchargée mesurée au POC primaire, divisée par l'énergie électrique absorbée, mesurée à tous les POC (primaires et auxiliaires), sur un cycle de charge/décharge normal d'un système EES dans les conditions de fonctionnement spécifiées

Note 1 à l'article: Le POC auxiliaire est utilisé pour la fourniture d'électricité aux composants auxiliaires et aux dispositifs tels que les instruments, les commandes, les fonctions de surveillance et de sécurité.

3.1.26
historique de fonctionnement
registre des conditions de fonctionnement du système

3.1.27
régime permanent
état d'un système ESS dans lequel les caractéristiques pertinentes restent constantes dans le temps

[SOURCE: IEC 60050-485:2020, 485-21-05, modifié – Dans la définition, "physique" a été remplacé par "EES"]

3.1.28
temps de commutation
durée exigée pour faire passer un système EES utilisant de l'hydrogène d'une phase de charge spécifiée à une phase de décharge spécifiée, ou inversement

Note 1 à l'article: Ce temps de commutation peut être important dans le cas où il est exigé que l'entretien du réseau soit effectué avec le système EES. Il comprend la durée exigée pour passer d'un point de fonctionnement en mode charge ou décharge à l'état de veille, la purge des conduites de gaz le cas échéant, le réglage des composants auxiliaires (soupapes, éléments chauffants, compresseurs, etc.) le cas échéant, et pour passer à un point de fonctionnement dans la phase opposée (décharge ou charge).

3.1.29
état d'essai
état du système EES soumis à l'essai conforme à l'objectif de l'évaluation

3.1.30
système soumis à l'essai
système EES défini par ses limites par rapport à l'environnement, conforme à l'objectif de l'évaluation

3.1.31
système de gestion de l'eau
sous-système du système EES utilisant de l'hydrogène, destiné à contrôler le débit d'eau et/ou le débit de vapeur dans le système EES

Note 1 à l'article: Le système de gestion de l'eau comprend les mécanismes de contrôle de l'entrée d'eau, ainsi que de son transport, sa purification (le cas échéant) et sa vidange.

3.2 Symboles

Le Tableau 1 énumère les symboles et les unités utilisés dans le présent document.

Tableau 1 – Symboles

Symbole	Définition	Unité	Formule	Figure
k	Facteur d'élargissement			
$m_{\text{H2,in}}$	Masse d'hydrogène fourni au système au POC	g	(4)	
n	Nombre de mesures jusqu'à la fin de la décharge		(3), (4)	
P_{el}	Puissance électrique au POC	W	(2)	
$P_{\text{el,loss}}$	Taux de perte à l'état de veille	W	(6)	
$P_{\text{el,in}}$	Puissance électrique nette d'entrée	W		
$P_{\text{el,out}}$	Puissance électrique nette de sortie	W	(3)	
$\mathrm{d}P/\mathrm{d}t$	Taux de rampe	W/s	(2)	Figure 5
$P_{\text{th,in}}$	Chaleur fournie	W		
$P_{\text{th,out}}$	Chaleur produite	W		
$q_{m,\text{H2,in}}$	Débit massique d'hydrogène à l'entrée du système au POC	g/s	(4)	
$q_{m,\text{H2,out}}$	Débit massique d'hydrogène à la sortie du système au POC	g/s		
t_0	Instant où le système, qui est en régime permanent, reçoit la valeur du point de consigne	s	(1)	Figure 4
t_1	Instant où la puissance électrique au POC devient inférieure à 90 % pour un état négatif ou supérieure à 10 % pour un état positif de la valeur du point de consigne	s	(2)	Figure 4
t_2	Instant où la puissance électrique au POC devient inférieure à 10 % pour un état négatif ou supérieure à 90 % pour un état positif de la valeur du point de consigne	s	(2)	Figure 4
t_3	Instant où la puissance électrique au POC atteint la valeur du point de consigne ±2 %	s	(1)	Figure 4
t_{loss}	Temps de mesure de l'autodécharge	h	(6)	
t_{so}	Temps de commutation	s		Figure 6
t_{sr}	Temps de réponse à un échelon	s	(1)	Figure 5

Symbole	Définition	Unité	Formule	Figure
W_{el}	Capacité de stockage de l'énergie électrique	Wh	(3)	
$W_{el,in}$	Énergie électrique d'entrée	Wh	(5), (6)	
$W_{el,out}$	Énergie électrique nette de sortie	Wh	(3)	
Δt	Temps d'échantillonnage de la mesure	h, s	(3)	
η_{el}	Rendement électrique aller-retour	%	(5)	

4 Instruments et méthodes de mesure

4.1 Généralités

Pour mesurer certaines propriétés du système EES soumis à l'essai, la configuration de ses composants et les conditions limites par rapport à l'environnement doivent être déterminées en premier lieu.

La définition claire du système EES soumis à l'essai exige une attention particulière. Les composants du système EES soumis à l'essai et les conditions de l'environnement d'essai à tous les points de connexion (POC) doivent être définis. Les POC sont les connexions d'entrée et de sortie pour l'électricité, la chaleur, l'eau, l'hydrogène, l'oxygène et l'air. Les conditions limites applicables à tous les POC doivent être définies.

L'état d'essai du système EES doit ensuite être défini. L'état d'essai du système ESS correspond aux niveaux de fonctionnement par rapport à la capacité maximale du système EES ou de l'un de ses composants au moment de la réalisation de l'essai.

Les conditions de fonctionnement applicables à l'essai doivent ensuite être définies. Elles doivent être convenues entre le fabricant du système EES et le client.

Les durées de fonctionnement doivent être relevées pendant la réalisation des essais. Elles se composent des temps d'entrée et de sortie électriques, des périodes de veille en entrée et en sortie, ainsi que des modèles de combinaison de ces paramètres. L'historique de fonctionnement et la durée réelle de fonctionnement du système affectent l'évaluation des performances du système EES. Par conséquent, l'historique des durées de fonctionnement du système EES avant l'exécution de l'essai doit également être consigné.

Lorsqu'il n'est pas possible d'effectuer des mesures de la puissance électrique ou du flux média à pleine échelle en raison de la taille importante du système, pour des motifs de sécurité ou en cas d'absence des instruments appropriés, des mesures peuvent être effectuées au niveau du sous-système. Ces mesures doivent permettre de déterminer des données représentatives des mesures à la taille réelle du système. Le concept de mesure appliqué doit être détaillé dans le rapport d'essai (voir 7.4).

4.2 Incertitude des instruments

L'incertitude élargie de chaque instrument de mesure (facteur d'élargissement $k = 2$) au moment de l'étalonnage, ou l'incertitude estimée à partir de la classe d'instrument doit satisfaire aux exigences suivantes:

- puissance électrique: ±2 % de la valeur lue;
- courant: ±1 % de la valeur lue;
- tension: ±1 % de la valeur lue;
- débit massique: ±1 % de la valeur lue;
- température ambiante: ±1 %;

– pression ambiante: ±0,1 kPa;
– humidité relative ambiante: ±5 %.

Les instruments qui satisfont aux exigences ci-dessus doivent être utilisés. L'ISO/IEC Guide 98-3 doit s'appliquer.

4.3 Plan de mesure

La configuration des composants, les conditions limites par rapport à l'environnement du système EES soumis à l'essai et l'état d'essai doivent être clairement définis. L'état d'essai doit être considéré au regard de l'application et de l'utilisation. De même, il convient de tenir compte des phases d'essai représentées à la Figure 3 qui comprennent la charge, le stockage et la décharge.

Les conditions de fonctionnement assignées et les conditions de fonctionnement limites du système EES soumis à l'essai font l'objet d'une confirmation entre le fabricant du système et le client. Les spécifications des fabricants des composants doivent permettre d'établir les conditions de fonctionnement assignées et les conditions de fonctionnement limites pour chaque composant.

La séquence des mesures doit ensuite être planifiée. Des propriétés spécifiques de certains composants doivent être prises en compte en fonction des conditions ou des paramètres applicables à d'autres composants. Par exemple, l'état de fonctionnement de la capacité de stockage de l'hydrogène se rapporte aux paramètres des conditions de fonctionnement de l'électrolyseur. Il convient également d'accorder une attention particulière au fait que certaines propriétés peuvent varier de manière significative au cours de la mesure. Par exemple, la puissance électrique d'entrée peut varier pendant la phase de charge. L'état d'essai doit être clairement défini et les changements de propriétés pendant la mesure doivent être identifiés. Pour établir les méthodes et les instruments de mesure, l'incertitude des instruments et la variation admissible doivent être vérifiées et consignées dans un rapport. Le Tableau 2 récapitule les actions préalables à mener avant la mesure.

La mesure de vérification des performances du système EES est effectuée après confirmation que le système EES fonctionne à l'état d'essai.

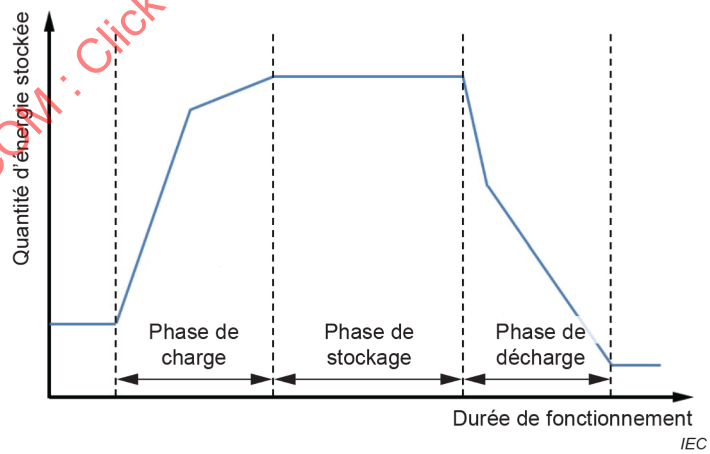


Figure 3 – Séquence type de phases pendant le fonctionnement du système