

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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 membranes, including reversible operation**

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**



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IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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 membranes, including reversible operation

FOREWORD

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International Standard IEC 62282-8-102 has been prepared by IEC technical committee 105: Fuel cell technologies.

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

FDIS	Report on voting
105/763/FDIS	105/776/RVD

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

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

A list of all parts in the IEC 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 "<http://webstore.iec.ch>" in the data related to the specific document. At this date, the document will be

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INTRODUCTION

This part of IEC 62282 describes test methods for a single cell and stack (denoted as "cell/stack" hereafter) that are intended for use in energy storage systems that use proton exchange membrane fuel cells (PEMFC) in combination with proton exchange membrane water electrolyzers (PEMWE), or directly using proton exchange membrane cells (Re-PEM).

This document is intended to be used for data exchanges in commercial transactions between cell/stack manufacturers and system developers or for acquiring data on a cell or stack in order to estimate the performance of a system based on it. Users of this document can selectively execute test items suitable for their purposes from those described in this document.

PEMFCs, PEMWEs and Re-PEMs have a broad range of geometry and size. As such, in general, peripherals like current collectors and gas manifolds are unique to each cell or stack and are often incorporated into a cell or stack to form one integrated unit. In addition, they tend to have a significant effect on the power generation characteristics of the cell or stack. This document therefore introduces as its subject "cell/stack assembly unit", which are defined as those units containing not only a cell or a stack, but also peripherals.

IEC 62282-8 (all parts) aims to develop performance test methods for power storage and buffering systems based on electrochemical modules (combining electrolysis and fuel cells, in particular reversible fuel 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 membranes, 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 62282-8-202²: *Power-to-power systems – Safety*
- IEC 62282-8-300 (all parts)³: *Power-to-substance systems*

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 have been initiated jointly and as a priority. These parts are presented as a package to highlight the need for an integrated approach as regards the system 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 Under consideration.

² Under consideration.

³ Under consideration.

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 membranes, including reversible operation

1 Scope

This part of IEC 62282 deals with PEM cell/stack assembly units, testing systems, instruments and measuring methods, and test methods to test the performance of PEM cells and stacks in fuel cell mode, electrolysis and/or reversible mode.

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 60050-485:—⁴, *International Electrotechnical Vocabulary – Part 485: Fuel cell technologies*

IEC TS 62282-7-1:2017, *Fuel cell technologies – Part 7-1: Test methods – Single cell performance tests for polymer electrolyte fuel cells (PEMFC)*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-485 and the following apply.

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

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

3.1.1

active electrode area

geometric area of the electrode perpendicular to the direction of the current flow

Note 1 to entry: Usually this corresponds to the smaller of the two areas of negative electrode or positive electrode.

[SOURCE: IEC 60050-485:—, 485-02-08, modified – "electrode" added to the term, the term "effective area" has been deleted, and the notes to entry have been replaced with a new note to entry.]

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

3.1.2**area-specific resistance****ASR**

internal resistivity with respect to the active electrode area, including the change of potential due to the electrochemical reaction

Note 1 to entry: This note applies to the French language only.

3.1.3**catalyst**

substance that accelerates (increases the rate of) a reaction without being consumed itself

Note 1 to entry: The catalyst lowers the activation energy of the reaction, allowing for an increase in the reaction rate.

3.1.4**catalyst-coated membrane****CCM**

<in a PEMFC (3.1.24)> polymer membrane whose surfaces are coated with a catalyst layer (3.1.5) to form the reaction zone of the electrode (3.1.8)

Note 1 to entry: See also membrane electrode assembly (MEA) (3.1.17).

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

[SOURCE: IEC 60050-485:—, 485-04-03]

3.1.5**catalyst layer**

surface porous region adjacent to either side of the membrane containing the catalyst (3.1.3), typically with ionic and electronic conductivity

Note 1 to entry: The catalyst layer comprises the spatial region where the electrochemical reactions can take place.

3.1.6**current collector**

conductive material in a fuel cell (3.1.13) that collects electrons from the negative electrode (3.1.20) side or conducts electrons to the positive electrode (3.1.25) side

3.1.7**current density**

current per unit active area (IEV 485-02-08)

Note 1 to entry: Current density is expressed in A/m² or A/cm².

3.1.8**electrode**

electronic conductor (or semi-conductor) through which an electric current enters or leaves the electrochemical cell as the result of an electrochemical reaction

Note 1 to entry: An electrode is either a positive electrode (3.1.25) or a negative electrode (3.1.20).

3.1.9**electrolyte**

liquid or solid substance containing mobile ions that render it ionically conductive

Note 1 to entry: The electrolyte is the main distinctive feature of the different fuel cell technologies (e.g. a liquid, polymer, molten salt, solid oxide) and determines the usable operating temperature range.

3.1.10

end plate

component located on either end of the cell stack in the direction of current flow, serving to transmit the required compression to the stacked cells

Note 1 to entry: The end plate can comprise ports, ducts, and manifolds for the supply of fluids (reactants, coolant) to the cell stack.

[SOURCE: IEC 60050-485:—, 485-06-06, modified – The admitted terms have been deleted, "fuel cell stack" has been replaced by "cell stack in the direction of current flow" in the definition, and the second sentence of Note 1 to entry has been deleted.]

3.1.11

flow plate

electronically conductive plate which incorporates channels for fuel (3.1.12) or oxidant (3.1.22) gas flow in fuel cell mode, while for water and gas flow in electrolysis mode and which comprises an electric contact with an electrode (3.1.8)

Note 1 to entry: The conductive plate material can be metal, a material such as graphite, or a conductive polymer that can be a carbon-filled composite.

3.1.12

fuel

hydrogen or hydrogen-containing gas that reacts at the negative electrode (3.1.20) in a fuel cell (3.1.13)

3.1.13

fuel cell

electrochemical device that converts the chemical energy of a fuel (3.1.12) and an oxidant (3.1.22) to electric energy (direct current (DC) power), heat and reaction products

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

[SOURCE: IEC 60050-485:—, 485-08-01]

3.1.14

gas diffusion electrode

GDE

type of electrode specifically designed for gaseous reactants or products or both

Note 1 to entry: A gas diffusion electrode usually comprises one or more porous layers, like the gas diffusion layer (3.1.15) and the catalyst layer (3.1.5).

Note 2 to entry: Gas diffusion electrodes can be negative gas diffusion electrodes and positive gas diffusion electrodes.

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

[SOURCE: IEC 60050-485:—, 485-02-02, modified – The abbreviated term "GDE" has been added, and "anodes" and "cathodes" have been replaced by "negative ... electrodes" and "positive ... electrodes" in Note 2 to entry.]

3.1.15

gas diffusion layer

GDL

porous substrate placed between the catalyst layer (3.1.5) and the flow plate (3.1.11) to serve as electric contact and allow the access of reactants to the catalyst layer and the removal of reaction products

Note 1 to entry: The gas diffusion layer is a component of a gas diffusion electrode (3.1.14).

Note 2 to entry: The gas diffusion layer is also called a porous transport layer (PTL).

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

[SOURCE: IEC 60050-485:—, 485-04-05, modified – "Bipolar plate" has been replaced by "flow plate" in the definition, and Note 2 to entry has been added.]

3.1.16

internal resistance

ohmic resistance inside a fuel cell (3.1.13), measured between current collectors (3.1.6), caused by the electronic and ionic resistances of the different components (electrodes, electrolyte, flow plates and current collectors)

Note 1 to entry: The term ohmic refers to the fact that the relation between voltage drop and current is linear and obeys Ohm's law.

[SOURCE: IEC 60050-485:—, 485-15-04]

3.1.17

membrane electrode assembly

MEA

component of a PEMFC (3.1.24) consisting of an electrolyte membrane, electrode and gas diffusion layer (3.1.15) on either side or a component of a PEMWE (3.1.26) consisting of an electrolyte membrane with catalyst layers (3.1.5) on either side.

Note 1 to entry: This note applies to the French language only.

[SOURCE: IEC TS 62282-7-1:2017, 3.19, modified – "or a component of a PEMWE...on either side" has been added.]

3.1.18

minimum cell voltage

lowest permitted fuel cell voltage specified by the manufacturer

3.1.19

maximum cell voltage

highest electrolyser voltage specified by the manufacturer

3.1.20

negative electrode

electrode (3.1.8) at which hydrogen gas is consumed or produced

Note 1 to entry: It is also called hydrogen electrode. In fuel cell mode it is called the anode, where the hydrogen is oxidized. In electrolysis mode, it is called the cathode, where water is reduced producing hydrogen.

Note 2 to entry: In fuel cell mode, the negative electrode gas is usually hydrogen or a mixture which contains hydrogen as a principal component mixed with water vapour and/or inert gas.

3.1.21

open circuit voltage

OCV

voltage across the terminals of a fuel cell (3.1.13) with fuel (3.1.12) and an oxidant (3.1.22) present and in the absence of external current flow

Note 1 to entry: The open circuit voltage is expressed in V.

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

[SOURCE: IEC 60050-485:—, 485-13-02, modified – The term "no-load" voltage has been deleted.]

3.1.22**oxidant**

oxygen or oxygen-containing gas (e.g. air) that reacts at the positive electrode (3.1.25) in fuel cell mode

3.1.23**polymer electrolyte**

polymer material containing mobile ions that render it ionically conductive

[SOURCE: IEC 60050-485:—, 485-03-01, modified – In the definition, "liquid or solid substance" has been replaced by "polymer material".]

3.1.24**proton exchange membrane fuel cell****PEMFC**

fuel cell (3.1.13) that employs a polymer with (proton) ionic exchange capability as the electrolyte (3.1.9)

Note 1 to entry: This note applies to the French language only.

[SOURCE: IEC 60050-485:—, 485-08-08, modified – The admitted term "solid polymer fuel cell" has been deleted, and the term "polymer electrolyte fuel cell" has been deleted.]

3.1.25**positive electrode**

electrode (3.1.8) at which oxygen is consumed or produced

Note 1 to entry: It may also be called oxygen electrode. In fuel cell mode it is called cathode where oxygen is reduced producing water. In the electrolysis mode, it is called anode where oxygen and protons are formed from water.

3.1.26**proton exchange membrane water electrolyser****PEMWE**

electrolyser that employs a polymer with (proton) ionic exchange capability as the electrolyte (3.1.9)

Note 1 to entry: This note applies to the French language only.

3.1.27**power density**

ratio of the electric power to the active electrode area (3.1.1) of the cell/stack assembly unit electrodes

3.1.28**rated current density**

maximum current density specified by the manufacturer, at which the cell/stack (3.1.32) assembly has been designed to operate continuously

3.1.29**reactant utilization**

ratio of converted substance flow through a given electrode of the cell/stack assembly unit to the input substance flow of the same electrode

Note 1 to entry: The three types of reactant utilization are:

- fuel (hydrogen) utilization (negative electrode in PEMFC mode);
- oxygen utilization (positive electrode in PEMFC mode);
- water conversion (positive electrode in PEMWE mode).

Note 2 to entry: In PEMFC mode, the effective reactant utilization can also be calculated as the ratio of actual output current of the cell/stack assembly unit to the theoretical Faradaic current.

3.1.30

reversible proton exchange membrane cell

RPEMC

Re-PEM

cell composed of three functional elements: negative electrode (3.1.20), proton exchange membrane electrolyte and positive electrode (3.1.25)

Note 1 to entry: Re-PEM can be used in fuel cell mode (PEMFC) or in electrolysis mode (PEMWE).

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

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

3.1.31

stable state

condition of a cell/stack assembly unit stable enough for any controlling parameter and the output/input voltage or output/input current of the unit to remain within its tolerance range of variation

3.1.32

stack

assembly of cells, separators, cooling plates, end plates, manifolds and a supporting structure that is used as a fuel cell (PEMFC) and/or a water electrolyser (PEMWE)

3.1.33

test input parameter

TIP

parameters whose values can be set in order to define the test conditions of the test system including the operating conditions of the test object

Note 1 to entry: TIPs have to be controllable and measurable. Values of TIPs are known before conducting the test. TIPs can be either static or variable. Static TIPs shall remain constant and variable TIPs are varied during the test.

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

3.1.34

test output parameter

TOP

parameters that indicate the response of the test system/test object as a result of variation of one or more TIPs

Note 1 to entry: Values of TOPs are unknown before conducting the test and will be measured during the test. TOPs need to be measurable.

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

3.1.35

dwelt time

time between changes in the setting of operating conditions

3.2 Symbols

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

Table 1 – Symbols

Symbol	Definition	Unit
a	Error limit specified from specification of instrument	-
A_{active}	Active electrode area of the cell/stack electrode(s)	cm ²
F	Faraday constant (96485,3)	A·s/mol
F_{compr}	Compression force applied onto the cell/stack	N
I	Stack current	A
J	Stack current density	A/cm ²
k	Coverage factor	
n	Number of transferred electrons	-
N	Number of cells in a series connection	-
p	Pressure	kPa
$p_{\text{neg,in}}$	Fluid pressure at negative electrode inlet	kPa
$p_{\text{pos,in}}$	Fluid pressure at negative electrode inlet	kPa
$p_{\text{neg,out}}$	Fluid pressure at negative electrode outlet	kPa
$p_{\text{pos,out}}$	Fluid pressure at negative electrode outlet	kPa
P	Power	W
P_{d}	Electric power density	W/cm ²
P_{el}	Electric power	W
q_V	Volumetric flow rate	m ³ /s
$q_{V,i}$	Volumetric flow rate of fluid component i (STP ^b)	m ³ /s
$q_{V,\text{neg}}$	Volumetric flow rate of negative electrode fluid (STP ^b)	m ³ /s
$q_{V,\text{pos}}$	Volumetric flow rate of positive electrode fluid (STP ^b)	m ³ /s
$q_{V,\text{neg,in}}$	Total volumetric fluid flow rate at negative electrode inlet	m ³ /s
$q_{V,\text{pos,in}}$	Total volumetric fluid flow rate at positive electrode inlet	m ³ /s
$q_{V,i,\text{neg,in}}$	Volumetric flow rate of fluid component i at negative electrode inlet	m ³ /s
$q_{V,i,\text{pos,in}}$	Volumetric flow rate of fluid component i at positive electrode inlet	m ³ /s
$q_{V,\text{H}_2,\text{neg,out}}$	Volumetric flow rate of hydrogen at negative electrode outlet	m ³ /s
$q_{M,\text{H}_2,\text{neg,out}}$	Hydrogen molar flow rate at negative electrode outlet	mol/s
R_{as}	Area-specific resistance	Ω·cm ²
R_{int}	Internal resistance	Ω
R_{g}	Universal gas constant (8,314 5)	J/(mol·K)
t_{acq}	Data acquisition time	s
t_{op}	Operating time	s
t_0	Beginning of measurement	s
t_1	End of measurement	s
t_{dwell}	Dwell time at a given operating point	s
t_{eq}	Equilibration time at a given operating point	s
t_{acq}	Acquisition time at a given operating point	s
T	Temperature	°C
T_{cell}	Temperature of the PEM cell	°C
T_{EP}	End plate temperature of the stack	°C
$T_{\text{neg,in}}$	Temperature of negative electrode fluid at cell/stack inlet	°C

Symbol	Definition	Unit
$T_{\text{pos,in}}$	Temperature of positive electrode fluid at cell/stack inlet	°C
$T_{\text{neg,out}}$	Temperature of negative electrode fluid at cell/stack outlet	°C
$T_{\text{pos,out}}$	Temperature of positive electrode fluid at cell/stack outlet	°C
T_{stack}	Temperature of the PEM stack	°C
$T_{\text{stack,intern}}$	Internal stack temperature	°C
$T_{\text{TR,in}}$	Heat transfer fluid inlet temperature	°C
$T_{\text{TR,out}}$	Heat transfer fluid outlet temperature	°C
U_{neg}	Reactant utilization at the negative electrode (fuel utilization in fuel cell mode)	-
U_{pos}	Reactant utilization at the positive electrode (oxidant utilization in fuel cell mode)	-
$V_{\text{cell/stack}}$	Voltage of the cell/stack assembly unit	V
$V_{\text{cell},i}$	Voltage of the individual cell number i	V
V_{av}	Average voltage of all cells in the stack	V
x	Composition	
x_i	Molar fraction of component i	
$\Delta p_{\text{neg-pos}}$	Pressure difference between negative electrode compartment and positive electrode compartment	kPa
ΔP_{d}	Change in power density	W/cm ²
ΔR_{as}	Change in area-specific resistance	$\Omega \cdot \text{cm}^2$
ΔV	Change in voltage	V
ΔV_{Cl}	Instantaneous change in cell voltage when the current is switched off	V
$\Delta Y/\Delta t$	Degradation rate ^a	
^a The quantity Y chosen for calculating the degradation rate can be the cell or stack voltage, the power density or the ASR.		
^b See 3.3.		

3.3 Standard temperature and pressure (STP) values for gas temperature and pressure

The reference gas conditions are specified as follows:

- $T_0 = 273,15 \text{ K}$;
- $p_0 = 101,325 \text{ kPa}$.

4 General safety considerations

An operating PEM cell/stack assembly unit uses or produces oxidizing and reducing, combustible gases. Typically, these gases are stored in high-pressure containers. The PEM cell/stack assembly unit itself can be operated at a pressure greater than atmospheric pressure.

The test personnel are responsible for obtaining and following all applicable safety codes and generally accepted engineering practices related to their test system, facility, fuels (with particular attention to compressed gases), and exhaust products. Those who carry out PEM cell/stack assembly unit testing shall be trained and experienced in the operation of test systems and specifically in safety procedures.

Materials which are compatible with the use and storage of the reactant gases shall be used during testing. Local safety codes and standards for working with hydrogen shall be followed.

Nevertheless, a number of empirical guidelines can be given for good practice while carrying out the experimental tests, which can help identify potentially hazardous situations. Operating conditions of the PEM cell/stack assembly unit have to be carefully monitored, in order to prevent safety-related issues, by use of an appropriate emergency shutdown system.

- Gas sensors: It is recommended to have gas sensors in close proximity to the test station (in particular for H_2), which are connected to an automated emergency shutdown system that cuts off the fuel feed to the test station if leakage of hazardous gases is detected.
- Protection gas emergency supply: In the case of emergency shutdown, it is recommended that a line containing an inert, reducing gas (i.e. nitrogen) be employed for the flushing of the negative electrode side of the PEM cell/stack assembly unit. This helps to expel flammable reactants from the system.
- Exhausted hydrogen shall be adequately dealt with. For small hydrogen flow rates (relative to the confined space where testing takes place), it can be sufficient to dilute the exhaust gas from the negative electrode with air or inert gas before venting. If large stacks are used, it is advised to adopt a (catalytic) afterburner before venting.
- Care shall be taken to ensure that oxygen produced in electrolysis mode is adequately dealt with. This shall be ventilated to the exterior in order to avoid accumulation of oxygen-enriched air, especially in confined spaces.
- For large stacks operated in fuel cell mode, care shall be taken to ensure that the positive electrode exhaust gas will be air depleted in oxygen, and therefore shall be adequately dealt with.
- Monitoring cell/stack voltage: A low open-circuit voltage (OCV) can be an indication of gas leakage from the cell/stack assembly. During the test operation (in closed circuit), it is advisable to monitor the cell/stack's closed-circuit voltage and implement an automated opening of the circuit if the measured cell/stack voltage falls outside of the predefined operating window.
- Pressure sensors could also assist to the control overpressures in the cell/stack assembly unit and to prevent a break in tightness.
- When operating the PEM cell/stack assembly unit in electrolysis mode, care should be taken to ensure that the produced hydrogen and the produced oxygen is adequately dealt with. The concentration of the produced hydrogen and oxygen shall be measured to avoid the concentration of the mixture of hydrogen and oxygen in the explosive range.
- In all cases, an adequate risk assessment that considers the place of testing and operating conditions should be conducted and appropriate risk reduction measures taken.

This by no means claims to be an exhaustive or even sufficient list for safe operation during testing. ISO/TR 15916 recommends "basic considerations for the safety of hydrogen systems"; however, measures for dealing with safety issues have to be drawn up in compliance with local legal requirements.

5 Test environment

5.1 General

The test environment consists of the test object (a PEM cell/stack assembly unit) mounted within the experimental set-up. The PEM cell/stack assembly unit consists of a cell or stack, fluid supply, current leads and such other peripherals as required for power generation or storage tests. It shall be provided with single or multiple measuring points for temperature and voltage and one set of current lead points, all to be specified by the manufacturer.

If the components of a cell/stack assembly unit other than a cell/stack are not specified by the manufacturer, unless proprietary, the following shall be described in the test report:

- components to be tested;
- flow pattern and direction of fluids;
- locations of temperature measurement, load application, voltage measurement and current extraction/supply;
- magnitude of the mechanical load;
- configuration of the assembly unit and its assembling method.

5.2 Reversible PEM cell/stack assembly unit

Figure 1 shows a reversible PEM cell/stack assembly unit, a number of MEA electric connected in series and/or parallel which are integrated between two end plates. The electrodes in the reversible PEM cell/stack assembly unit are the negative electrode and positive electrode, respectively.

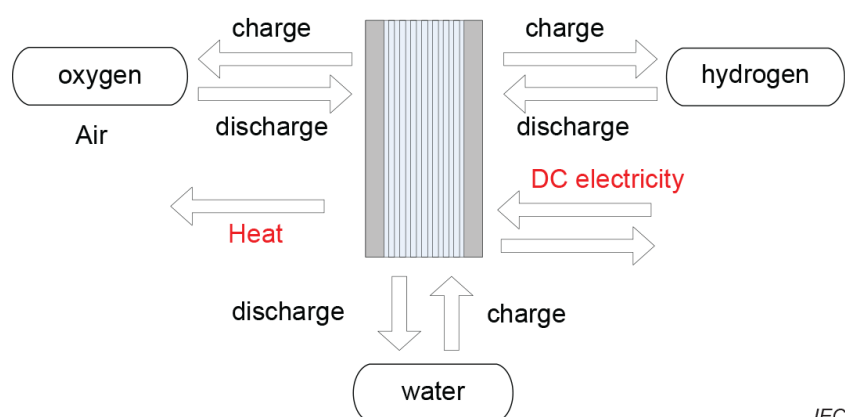


Figure 1 – Schematic representation of a reversible PEM cell/stack assembly unit

5.3 Separated reversible PEM cell/stack assembly unit

Figure 2 shows the schematic representation of a separated reversible PEM cell/stack assembly unit, consisting of a PEMFC and a PEMWE, which are connected by an oxygen tank, a hydrogen tank and a water tank.

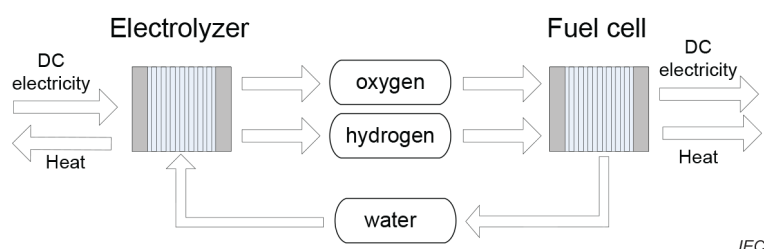


Figure 2 – Schematic representation of a separate reversible PEM cell/stack assembly unit

5.4 Experimental set-up

5.4.1 General

Figure 3 shows a complete test environment which consists of the PEM cell/stack assembly unit (test object) and the corresponding test and control equipment, divided into different subsystems. The test object is exposed to test inputs or operational conditions and delivers test outputs or test results.

The operation mode could be steady-state operation or dynamic operation.

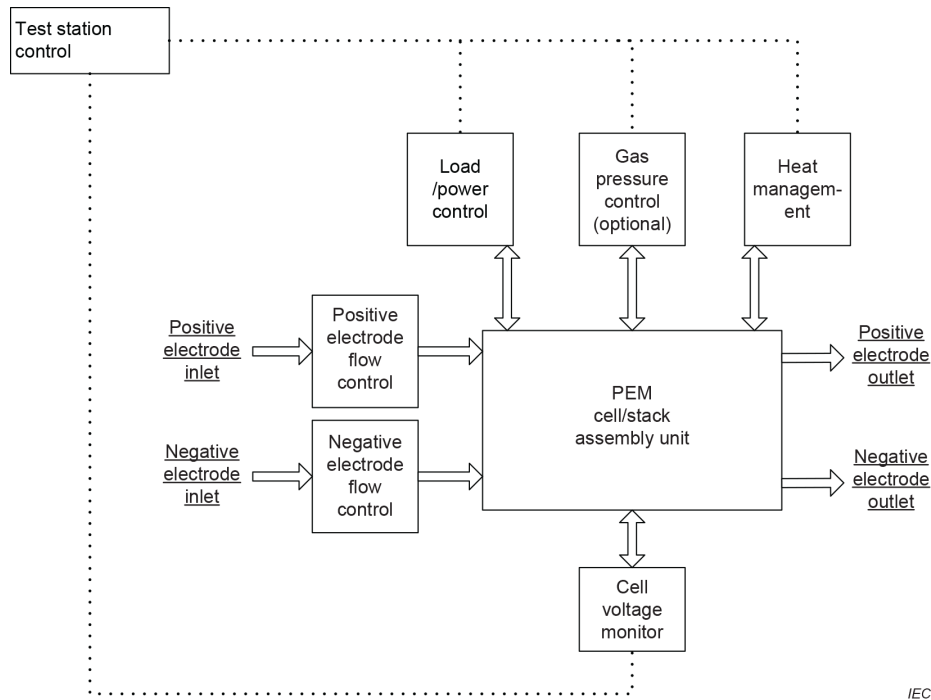


Figure 3 – Schematic graph of a test environment for a PEM cell/stack assembly unit

5.4.2 Fluid flow control equipment

The fluid flow control equipment controls the flow rate, composition and temperature of fluids supplied to the cell/stack assembly unit. The fluids comprise the positive and negative electrode gases (PEMFC) and deionized water (PEMWE).

5.4.3 Load/power control equipment

The load/power control subsystem controls the output/input current or output/input voltage of the cell/stack assembly unit.

5.4.4 Measurement and data acquisition equipment

The measurement and data acquisition equipment acquires and records:

- the cell/stack assembly unit temperature, current and voltage as well as individual cell voltages;
- the inlet fluid flow rates, composition, temperature;

and optionally:

- the environmental conditions (ambient temperature, relative humidity and atmospheric pressure)
- the mechanical load applied to the cell;
- the pressure of the gases (at inlet and/or outlet)
- the flow rate, composition and temperature of the outlet gases;
- the flow rate, composition and temperatures of the heat transfer fluid(s);
- cell/stack assembly unit impedance.

The data shall be recorded at appropriate sampling rates.

5.4.5 Safety equipment

The safety equipment shall consist of detectors, actuators and an alarm system for alerting malfunctioning of the test system based on predefined parameters and criteria. If it detects a serious fault, then it shall automatically establish a safe state in the test system. For safety reasons the electrode gases shall be purged with an inert gas. For the protection of the PEM cell/stack assembly unit, the inert gas may, as appropriate, also contain oxygen/hydrogen additions outside their respective higher flammable limit (HFL)/lower flammable limit (LFL).

5.4.6 Mechanical load control equipment

The optional, mechanical load control equipment regulates the mechanical load that is applied to increase the contact among components in the cell/stack assembly unit. The equipment shall be strong enough to apply the required mechanical load under the test conditions and to maintain the load for a long-term operation.

5.4.7 Heat management equipment

The heat management equipment controls the temperature of the PEM cell/stack assembly unit. It transfers heat from/to the PEM cell/stack assembly unit (PEMFC/PEMWE) via a heat transfer fluid.

5.4.8 Gas pressure control equipment

The optional, gas pressure control equipment regulates the pressure of the electrode gases.

5.4.9 Test system control equipment

The test system control equipment provides an integrated control for each control device and data acquisition device.

5.5 Parameter control and measurement

For the fluids at cell/stack inlet and/or outlet, the relevant parameters are:

- temperature, T ;
- flow rate (volume), q_V ;
- pressure, p ;
- composition, x .

The electrical interface parameters are:

- cell/stack current (common synonym is stack load), I ;
- cell/stack assembly unit voltage, $V_{\text{cell/stack}}$;
- voltage of the individual cells, $V_{\text{cell},i}$.

The heat interface parameters are:

- heat transfer fluid inlet temperature, $T_{\text{TR,in}}$;
- heat transfer fluid outlet temperature, $T_{\text{TR,out}}$;
- cell or stack internal temperature T_{cell} or T_{stack} .

The mechanical interface parameter is:

- cell or stack compression force, F_{compr} .

Ideally, the position for the setting/monitoring of the input/output parameter measurement device (sensor) is as close as possible to the boundary between the test object and the experimental set-up or where possible, within the boundary of the test object.

5.6 Measurement methods of TIPs and TOPs and control accuracy

The process of determining the precision, accuracy and uncertainty of TIPs and TOPs measurement is an extensive process beyond the scope of this document. Details can be found in the ISO/IEC Guide 98 series on the expression of uncertainty in measurement (GUM).

- Precision is the closeness of agreement between independent measurements of a quantity under the same conditions. It is a measure of how well a measurement can be made without reference to a theoretical or true value and depends only on the distribution of random errors.
- Accuracy is the closeness of agreement between a measured value and the true value. Error is the difference between a measurement and the true value of the quantity being measured.
- Uncertainty is the component of a reported value that characterizes the range of values within which the true value is asserted to lie. An uncertainty estimate shall address error from all possible effects (both systematic and random) and, therefore, usually is the most appropriate means of expressing the accuracy of results.

Based on the aforementioned definitions, it is clear that the most appropriate means of expressing the values of TOPs is the uncertainty of the measured values, while for the TIPs, the control accuracy (which is usually instrument specific) shall be reported.

6 Measurement instruments and measurement methods

6.1 Instrument uncertainty

The measuring parameters listed in Table 2 shall be recorded and stored with a sampling rate fast enough to ensure that all relevant changes in the parameters are recorded for later data analysis. The sampling rate frequency is recommended to be 1 Hz or higher.

The expanded uncertainty of each measuring instrument (coverage factor $k = 2$, see ISO/IEC Guide 98-3) at the time of calibration or that estimated from the class of instrument shall meet as a minimum the requirements indicated in Table 2.

Table 2 – Instrument uncertainty for each quantity to be measured

Symbol	Quantity	Instrument uncertainty
I	Current	± 1 % relative to rated
V	Voltage	$\pm 0,5$ % relative to OCV (for fuel cell mode) or maximum cell/stack voltage (for electrolysis mode)
T	Temperature	± 1 K
$q_{V,neg,pos,in/out}$	Volumetric flow rate	± 2 % of rated
x_i	Molar fraction	± 2 mol %
x_{O_2}	Oxygen molar fraction	$\pm 0,3$ mol % relative to O_2 concentration (balance in N_2)
$p_{neg,pos,in/out}$	Pressure	± 2 % of maximum expected value
NOTE The uncertainties for current and voltage refer to their respective DC parts and do not provide suitable values for these quantities in impedance measurements.		

Each measuring instrument shall be checked for its last calibration, the uncertainty under the calibration conditions, or estimated from the class of the instrument, and its dependency on the environmental conditions in order to estimate the uncertainty of the instrument. The method and cycle of calibration and replacement shall be designed to ensure that there is no increase in measurement uncertainty.

6.2 Recommended measurement instruments and methods

6.2.1 General

Measuring instruments shall be selected in accordance with the range of values to be measured. All measuring devices shall be calibrated according to the manufacturer's instructions or relevant national or international standards.

6.2.2 Voltage

A voltage meter shall be connected to the positive and negative flow plates or current collectors, minimizing the influence of electric contact resistances. The electric contact resistances between the connections of the voltage meter, either positive and negative flow plates or output terminals of positive and negative current collectors shall be measured and recorded, when not negligible.

The voltage may also be measured using the features of a potentiostatic/galvanostatic power supply (for electrolysis mode) or an electronic load (for fuel cell mode).

6.2.3 Current

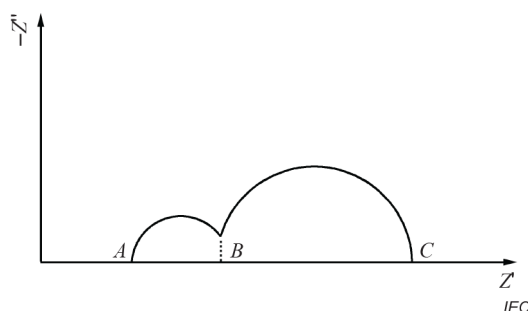
A current measuring device shall be located in the current-carrying circuit of the cell. The current-measuring device may consist of a low-impedance amperemeter or a calibrated shunt resistor, which develops a precisely known voltage in proportion to the current flowing.

The current may also be measured using the features of a potentiostatic/galvanostatic power supply (for electrolysis mode) or an electronic load (for fuel cell mode).

6.2.4 Internal resistance (IR)

The recommended IR measuring methods are the current interruption method and the electrochemical impedance spectroscopy (EIS) method.

Figure 4 shows a schematic diagram of PEM cell impedance (conjugate imaginary part of impedance versus real part of impedance). The intercept of the measured PEM cell impedance with the real impedance axis, generally included between 1 kHz and 20 kHz, identifies point *A*. The impedance measured or interpolated at point *A* represents the IR, consisting in a purely resistive impedance.



Key

A: high-frequency end impedance

C: low-frequency end impedance

A-B: high-frequency arc impedance

B-C: low-frequency arc impedance

Z': real part of impedance

Z'': imaginary part of impedance

Figure 4 – Schematic diagram of PEM cell impedance

In determining IR, care shall be taken in the selection of an appropriate frequency to ensure the impedance contains no imaginary component.

Care shall be taken when using an external AC signal in parallel with the load in order to avoid interference.

Plus/minus sense leads of these measuring instruments shall be connected to the output terminals of the positive and negative current collectors, respectively.

Typical instrumentation for IR measurement is a combination of a potentiostat/galvanostat and a frequency analyzer.

6.2.5 Electrode gas flow rates

Electrode gas flow rates shall be measured by means of a volumetric meter, a mass flow meter, or a turbine-type flow meter. If such a method is not practical, flow measurement by a nozzle, orifices or a Venturi meter is recommended. In fuel cell mode, the location of the flow meter shall be upstream of the humidifier of the supplied gases. In electrolysis mode, the location of flow meter shall be downstream of the dehumidifier of the product gases.

If the flow meter requires pressure compensation, a static pressure measuring port shall be located immediately upstream of the flow meter to be corrected.

If the flow meter requires temperature compensation, the sensor for such correction shall be located immediately upstream of the flow meter.

6.2.6 Electrode gas temperature

The recommended sensor for direct temperature measurement is a thermocouple, a resistance thermometer with a transducer or a thermistor.

The temperature sensor shall be located immediately downstream of the cell/stack assembly unit. It is recommended to position another sensor immediately upstream of the cell/stack assembly unit.

6.2.7 Cell/stack temperature

The recommended sensor for direct temperature measurement is a thermocouple, a resistance thermometer with a transducer or a thermistor.

For measuring the cell temperature, a temperature sensor shall be placed as close as possible to the centre of the electrodes active area. Ideally, it shall be at the centre of both positive and negative flow plates (see 5.5 and Annex A for more details).

For measuring the stack temperature, temperature sensors may be placed at the electrode outlets and/or the coolant medium outlet as appropriate.

6.2.8 Electrode gas pressures

For measuring electrode gas pressures, calibrated pressure transducers are the preferred method. Other acceptable methods include calibrated manometers, dead-weight gauges, Bourdon tubes or other elastic-type gauges.

Static pressure-measuring ports shall be located immediately upstream or immediately downstream of the cell/stack assembly unit. Electrode gas pressures may be controlled either upstream of the cell (inlet pressure mode) or downstream of the cell (back pressure mode).

Connecting piping shall be checked to verify that it is leak-free under working conditions in advance of the performance tests. Liquid water in the piping shall be avoided.

If pressure fluctuations occur, a suitable means of damping shall be installed in an effective position.

Pressures shall be measured as static pressures with the effect of velocity considered and eliminated.

6.2.9 Electrode gas humidity

To measure electrode gas humidity, a chilled mirror, aluminum oxide, bulk polymer resistive or capacitance-type hygrometer can be used to obtain humidity values, depending on the fuel and oxidant temperatures.

Humidity shall be expressed as a dew-point temperature or as relative humidity in percent calculated at the fuel cell's temperature.

A humidity measuring port shall be located upstream of the cell/stack assembly unit, or the humidity sensor can be in the reactant gas before testing commences. In the case of using ambient or synthetic air as oxidant, the dew point shall be measured and recorded.

6.2.10 Ambient conditions

It is recommended that the ambient temperature, pressure and humidity be measured and recorded.

For the direct measurement of ambient temperature, thermocouples with a transducer or a resistance thermometer with a transducer is recommended.

For the direct measurement of ambient pressure, a mercury-free barometer is recommended.

For direct measurement of ambient humidity, a hygrometer is recommended.

6.3 Reference test conditions and manufacturer recommendations

6.3.1 Start-up and shut-down conditions

The start-up conditions and the shut-down conditions shall be based on those recommended by the manufacturer or the results of preliminary tests.

6.3.2 Range of test conditions

The reference test conditions and the typical test range that are recommended by the cell/stack assembly unit manufacturer shall be reviewed for the following parameters in order to determine the test conditions and range:

- a) cell/stack assembly unit temperature;
- b) allowable cell/stack assembly unit temperature distribution (for multiple measuring points);
- c) negative electrode fluid flow rate;
- d) negative electrode fluid composition;
- e) negative electrode fluid pressure;
- f) positive electrode fluid flow rate;
- g) positive electrode fluid composition;
- h) positive electrode fluid pressure;
- i) fuel utilization at the negative electrode (fuel cell mode);
- j) oxidant utilization (fuel cell mode);
- k) current or current density;
- l) minimum cell/stack assembly unit voltage (fuel cell mode);
- m) maximum cell/stack assembly unit current (under a given hydrogen utilization in fuel cell mode); damage due to excessive degradation is possible beyond this value; and
- n) mechanical load.

6.3.3 Stabilization, initialization conditions and stable state

After start-up, the manufacturer may recommend a period of stabilization, or initialization before the cell/stack assembly unit is ready for characterization. Alternatively, this can be based on preliminary tests, to ensure that the drift of the output concerned at the time of measurement – due to on-going stabilization or initialization of the cell/stack assembly unit – is insignificant.

Once the cell/stack assembly unit is initialized, the tolerance level as a variation of the output current or output voltage of the cell/stack assembly unit shall be determined, and the resulting acceptance criteria for stable state shall be defined.

6.4 Data acquisition method

Preliminary tests shall be conducted while taking into consideration the variation of each test parameter and the sampling rate of each measuring instrument, to determine the sampling interval and the number of samplings and measurements. The sampling interval (e.g. 1 s) shall be short enough to observe the variation for a single measurement parameter with sufficient time resolution. The number of samplings and repetitions for a single measurement shall be decided so that the total measurement period becomes sufficiently longer than the dominant variation cycle of each test parameter.

7 Test procedures and computation of results

7.1 General

Owing to the intrinsic functionality of a PEM cell/stack assembly unit, the following test procedures may address different operation modes: fuel cell mode (PEMFC), electrolysis mode (PEMWE) and combined or reversible mode (Re-PEM). Each of these cases will investigate performance and durability, and can be tailored to fit a specific test objective, reflecting, for example, a typical application, such as peak power shaving. In the frame of this document, the objective is to align the following test procedures as much as possible with the requirements of systems for power storage and buffering (see IEC 62282-8-201). Test procedures already described in IEC TS 62282-7-1 and that are directly applicable to PEM cell/stack assembly units operated in reversible mode are not repeated in this document.

7.2 Current-voltage (I - V) characteristics test

7.2.1 Objective

The objective of this test is to characterize the response of a PEM cell/stack assembly unit while operating at different current densities either in fuel cell mode or in electrolysis mode. The test aims to measure the voltage of the PEM cell/stack assembly unit as a function of the current density (current-voltage characteristics or I - V curve). From the I - V curve resulting from this test, the area-specific resistance (ASR) can be computed.

7.2.2 Test method

The main action of the test is to determine the cell/stack assembly unit voltage at specified settings of current. The duration of the test depends on the measurement method (number of steps, current increasing/decrease rate) and whether a specified current or voltage is obtained. The unit shall be operated until the stable state is reached under open-circuit conditions (fuel cell mode), after which the current-voltage characteristics can be measured.

The test shall be carried out by changing the current stepwise, and recording the cell/stack assembly unit voltage. Measurements shall be taken when the cell/stack assembly unit reaches the stable state in each step, and at each step measurements are taken at the sampling intervals.

Alternatively, the voltage can be controlled and the current recorded. In both cases, instead of stepwise measurement, a sweep of the controlling parameter can be carried out at a constant speed. When a sweep is used, the sweep speed shall be determined such that the maximum width of the recorded parameter's hysteresis does not exceed the voltage variation in the stable state.

7.2.3 Data post-processing

The raw data post processing consists in calculating the average of the response values from all data sampled during acquisition time of each step (t_{acq}). Furthermore, the following results shall be computed and presented.

The electric power P_{el} and/or the power density P_d shall be calculated as output of this test, in accordance with Annex B.

The calculation for fuel utilization shall be performed in accordance with IEC 62282-7-1.

The results shall be plotted as PEM cell voltage, power density and PEM cell temperature(s) versus current density. In addition, fuel utilization (fuel cell mode) and/or hydrogen evolution (electrolysis mode), and/or oxidant utilization (fuel cell mode), and/or oxygen evolution (electrolysis mode) may be plotted. In general, the reported plots shall be representative of the targeted application/test objective.

All relevant test input parameters (TIPs), test output parameters (TOPs) and derived quantities for this test are provided in Clause A.3.

7.3 Steady-state test

7.3.1 Objective

The objective of this test is to verify the output from the cell under constant-current conditions with all test input parameters set to their specified values. This test can also be carried out under constant-voltage conditions.

7.3.2 Test methods

There are two similar methods to perform this test.

a) Constant current method

Set the current at a level corresponding to the rated current density and maintain it until it has reached a stable state as defined by the manufacturer or until the cell/stack voltage is stabilized within ± 5 mV. Subsequently carry out the test for a specified duration based on the objective of the test.

Record the cell/stack voltage.

b) Constant voltage method

Set the cell/stack voltage corresponding to the desired value and maintain it until it has reached a stable state as defined by the manufacturer or until the cell/stack current is stabilized within ± 2 %. Subsequently carry out the test for a specified duration based on the objective of the test.

Record the cell/stack current.

7.3.3 Data post-processing

The electric power output (fuel cell mode)/input (electrolysis mode) under the standard test conditions (P_{e1}) is calculated from the test results, in accordance with Annex B.

All relevant test input parameters (TIPs), test output parameters (TOPs) and derived quantities for this test are provided in Clause A.4.

7.4 Durability test

7.4.1 Objective

The objective of this test is to characterize the response of a PEM cell/stack assembly unit under constant conditions [constant current or reactant utilization (hydrogen or oxygen) in fuel cell mode and water in electrolysis mode]. The test aims to measure the long-term endurance of the cell/stack assembly unit at a given operating condition. From the voltage profile over time resulting from this test, the degradation rate can be computed.

7.4.2 Test method

The main action of the test is to determine the cell/stack assembly unit voltage at specified conditions (current or reactant utilization). The test shall be carried out by operating the cell/stack assembly unit at the specified settings of conditions either for a specified duration or until a specified voltage is obtained.

7.4.3 Data post-processing

A graph presenting the evolution of the cell/stack assembly voltages ($V_{\text{cell/stack}}$, $V_{\text{cell},i}$) as a function of time shall be reported. It is recommended to also provide a graph with the time-evolution of the unit temperatures (T_{cell} or T_{stack}).