



BSI Standards Publication

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

National foreword

This British Standard is the UK implementation of EN IEC 62282-8-101:2020. It is identical to IEC 62282-8-101:2020.

The UK participation in its preparation was entrusted to Technical Committee GEL/105, Fuel cell technologies.

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

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English Version

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 62282-8-101:2020)

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 62282-8-101:2020)

Brennstoffzellentechnologien - Teil 8-101:
Energiespeichersysteme mit Brennstoffzellenmodulen im
reversiblen Betrieb - Prüfverfahren zum Leistungsverhalten
von Festoxid-Einzelzellen und -Stacks einschließlich
reversiblen Betrieb
(IEC 62282-8-101:2020)

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

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

European foreword

The text of document 105/765/FDIS, future edition 1 of IEC 62282-8-101, prepared by IEC/TC 105 "Fuel cell technologies" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN IEC 62282-8-101:2020.

The following dates are fixed:

- latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement (dop) 2020-12-24
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2023-03-24

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Endorsement notice

The text of the International Standard IEC 62282-8-101:2020 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 62282-8-102	NOTE	Harmonized as EN IEC 62282-8-102
IEC 62282-8-201	NOTE	Harmonized as EN IEC 62282-8-201

Annex ZA

(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE 1 Where an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60050-485	-	International Electrotechnical Vocabulary - Part 485: Fuel cell technologies	-	-
IEC 61515	2016	Mineral insulated metal-sheathed thermocouple cables and thermocouples	EN 61515	2016
IEC 60584-1	-	Thermocouples - Part 1: EMF specifications and tolerances	EN 60584-1	-
IEC 60584-3	-	Thermocouples - Part 3: Extension and compensating cables - Tolerances and identification system	EN 60584-3	-
ISO 5168	-	Measurement of fluid flow - Procedures for the evaluation of uncertainties	-	-
ISO 6141	-	Gas analysis - Contents of certificates for calibration gas mixtures	EN ISO 6141	-
ISO 6142-1	-	Gas analysis - Preparation of calibration gas mixtures - Part 1: Gravimetric method for Class I mixtures	EN ISO 6142-1	-
ISO 6143	-	Gas analysis - Comparison methods for determining and checking the composition of calibration gas mixtures	EN ISO 6143	-
ISO 6145-7	-	Gas analysis - Preparation of calibration gas mixtures using dynamic volumetric methods - Part 7: Thermal mass-flow controllers	EN ISO 6145-7	-
ISO 6974	series	Natural gas - Determination of composition and associated uncertainty by gas chromatography	EN ISO 6974	series

EN IEC 62282-8-101:2020 (E)

ISO 7066-2	-	Assessment of uncertainty in the calibration and use of flow measurement devices - Part 2: Non-linear calibration relationships	-	-
ISO 8756	-	Air quality - Handling of temperature, pressure and humidity data	EN ISO 8765	-

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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**

FOREWORD

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International Standard IEC 62282-8-101 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
105/765/FDIS	105/779/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

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

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

INTRODUCTION

This document describes test methods for a single cell or stack (denoted as "cell/stack" hereafter) that are intended for application to energy storage systems using solid oxide fuel cells (SOFC) in combination with solid oxide electrolysis cells (SOEC), or directly using reversible solid oxide cells (Re-SOC, see Note in Clause 1). The test methods aim to provide guidelines for the characterization of real-time performance and durability of the cell/stack.

SOFC, SOEC and Re-SOC have a broad range of geometries (e.g. planar, tubular and their variations) 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 units", which are defined as those units containing not only a cell or a stack but also peripherals.

This document is generally applicable to all types or geometries of SOFC, SOEC and Re-SOC, unless where explicitly mentioned.

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 will consist 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 62282-8-103¹: *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 series³: *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 documents 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 reversible 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 8-101: 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

1 Scope

This part of IEC 62282 addresses solid oxide cell (SOC) and stack assembly unit(s). It provides for testing systems, instruments and measuring methods to test the performance of SOC cell/stack assembly units for energy storage purposes. It assesses performance in fuel cell mode, in electrolysis mode and/or in reversible operation.

This document is not applicable to small button cells that are designed for SOC material testing and provide no practical means of reactant utilization measurement, or to single-chamber SOC. This document is not intended to be applied to fuel cell/stack assembly units for power generation purposes only, since this is covered in IEC TS 62282-7-2. Therefore, test methods are not included in this document that are applicable to fuel cell mode only and that are already described in IEC TS 62282-7-2.

This document is intended 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 may selectively execute test items suitable for their purposes from those described in this document. Users can also substitute selected test methods of this document with equivalent test methods of IEC TS 62282-7-2 for SOC operation in fuel cell mode only.

NOTE 1 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 solid oxide cell that alternates between fuel cell mode and electrolysis mode "reversible".

NOTE 2 This document considers only steam electrolysis. Other reactants in electrolysis mode can be used, provided appropriate measures are taken for handling the specific reactants and products, and the guidelines as regards the measurement, control and post-test analysis of results are adapted accordingly.

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, *International Electrotechnical Vocabulary – Part 485: Fuel cell technologies* (available at www.electropedia.org)

IEC 61515:2016, *Mineral insulated metal-sheathed thermocouple cables and thermocouples*

IEC 60584-1, *Thermocouples – Part 1: EMF specifications and tolerances*

IEC 60584-3, *Thermocouples – Part 3: Extension and compensating cables – Tolerances and identification system*

ISO 5168, *Measurement of fluid flow – Procedures for the evaluation of uncertainties*

ISO 6141, *Gas analysis – Contents of certificates for calibration gas mixtures*



ISO 6142-1, *Gas analysis – Preparation of calibration gas mixtures – Part 1: Gravimetric method for Class I mixtures*

ISO 6143, *Gas analysis – Comparison methods for determining and checking the composition of calibration gas mixtures*

ISO 6145-7, *Gas analysis – Preparation of calibration gas mixtures using dynamic volumetric methods – Part 7: Thermal mass-flow controllers*

ISO 6974 (all parts), *Natural gas – Determination of composition with defined uncertainty by gas chromatography*

ISO 7066-2, *Assessment of uncertainty in the calibration and use of flow measurement devices – Part 2: Non-linear calibration relationships*

ISO 8756, *Air quality – Handling of temperature, pressure and humidity data*

3 Terms, definitions, abbreviated terms 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

effective electrode area

geometric area of the electrode where the electrochemical reaction takes place

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

Note 2 to entry: Area perpendicular to the ionic current flow, usually expressed in m^2 or cm^2 .

[SOURCE: IEC TS 62282-7-2:2014, 3.1.2, modified – Definition and Note 1 to entry reworded and Note 2 to entry added.]

3.1.2

area-specific resistance

ASR

R_{ASR}

internal resistivity of any component of a cell or a stack, including the change of potential due to the electrochemical reaction

Note 1 to entry: It is normalized by the active electrode area and is expressed in $\Omega \text{ m}^2$ or $\Omega \text{ cm}^2$.

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

3.1.3

average repeating unit voltage

average RU voltage

cell/stack assembly unit voltage divided by the number of the cells in a series connection in the unit

Note 1 to entry: Average voltage is expressed in V.

[SOURCE: IEC TS 62282-7-2:2014, 3.1.4 modified – In the term, word "cell" replaced by "repeating unit", and Note 1 to entry added.]

3.1.4

interconnector

interconnect

conductive and gas-tight component connecting single cells in a stack

Note 1 to entry: Gas tightness is relevant for planar-type geometries of SOC.

Note 2 to entry: This item is only applicable to planar-type geometries of SOC, as opposed to tubular geometries (see IEC 60050-485:—, 485-06-04).

[SOURCE: IEC 60050-485:—, 485-06-05, modified – Words "fuel cell stack" replaced by "stack", and Notes 1 and 2 to entry added.]

3.1.5

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.

[SOURCE: IEC 60050-485:—, 485-01-01, modified – Definition reworded, and Note 2 to entry removed.]

3.1.6

single cell

cell

basic unit of a solid oxide cell

3.1.7

axial load

compression force

compressive load applied to the single cell or the end plates of a planar SOC stack to ensure electric contact and/or gas tightness

Note 1 to entry: The compression force is in practice expressed in N.

[SOURCE: IEC 60050-485:—, 485-06-14, modified – Words "end plates of a fuel cell" replaced by "single cell or the end plates of a planar SOC", "electric" added, and Note to entry replaced.]

3.1.8

conditioning

preliminary step of treatment that is required to properly operate a SOC and is usually realized by following a protocol specified by the manufacturer

Note 1 to entry: The conditioning may include reversible and/or irreversible processes depending on the cell technology.

[SOURCE: IEC 60050-485:—, 485-11-08, modified – Words "of treatment" added, "fuel cell" replaced by "SOC", and "to achieve a desired performance" replaced by "and is usually realized by".]

3.1.9**contact layer**

layer applied between the interconnect and the cell to minimize the contact resistance

3.1.10**current collector**

electronically conductive material in a cell/stack assembly unit that collects/conducts electrons from/to the electrodes

[SOURCE: IEC 60050-485:—, 485-06-07, modified – Word "electronically" added, "fuel cell" replaced with "cell/stack assembly unit", and "anode/cathode" replaced with "electrodes".]

3.1.11**current density**

current per unit active area

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

[SOURCE: IEC 60050-485:—, 485-12-01, modified – Word "electric" deleted before "current".]

3.1.12**derived quantities**

quantities that can be derived or calculated from test input parameters, and/or test output parameters (e.g. current density, reactant utilization, electric efficiency)

Note 1 to entry: In comparison to test output parameters, derived quantities are not directly measurable.

3.1.13**dwelt time**

time between changes in the setting of operating conditions

3.1.14**electrode gas**

gas present at the positive or negative electrode

Note 1 to entry: Electrode gases can be reactants, products or inert gas.

3.1.15**reactant utilization**

effective 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 utilization (negative electrode in SOFC mode);
- oxygen utilization (positive electrode in SOFC mode);
- steam conversion (negative electrode in SOEC mode).

Note 2 to entry: In SOFC 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.

Note 3 to entry: Under the assumption that the electrolyte has neither leak nor electronic conductivity, the reactant utilization is equivalent to the effective reactant utilization and can be calculated according to IEC TS 62282-7-2:2014, Annex B and Annex C.

3.1.16

exhaust gas

gas which is exhausted from the electrodes of the SOC

Note 1 to entry: The exhaust gas is a mixture of the reaction products of the electrochemical reaction, not converted reactant gas and inert gases, which is supplied to the electrodes.

3.1.17

minimum voltage

<in SOFC mode> lowest cell/stack assembly unit voltage specified by the manufacturer

Note 1 to entry: Minimum voltage is expressed in V.

3.1.18

maximum voltage

<in SOEC mode> highest cell/stack assembly unit voltage specified by the manufacturer

Note 1 to entry: Maximum voltage is expressed in V.

3.1.19

negative electrode

electrode at which fuel gas is consumed or produced

Note 1 to entry: It may also be called fuel electrode. In fuel cell mode, it is called the anode, where the fuel is oxidized. In electrolysis mode, it is called the cathode, where steam 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.

Note 3 to entry: In electrolysis mode, the negative electrode gas is usually water vapour mixed with hydrogen and/or inert gas.

3.1.20

open-circuit voltage

OCV

voltage across the terminals of a SOC with positive and negative electrode gases present and in the absence of external current flow

Note 1 to entry: 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 – Words "fuel cell" replaced by "SOC", and "fuel and oxidant" replaced with "positive and negative electrode gases".]

3.1.21

positive electrode

electrode at which oxygen is consumed or produced

Note 1 to entry: Oxygen and nitrogen are the main components of positive electrode gases.

Note 2 to entry: In the case of a proton-conducting SOC, the mechanisms at electrodes, the ions crossing the electrolyte and the atmosphere at the electrodes will be different.

Note 3 to entry: It may also be called oxidant electrode. In fuel cell mode, it is called cathode where oxygen is reduced producing oxide ions going through the electrolyte. In electrolysis mode, it is called anode where two oxide ions are recombined to form one molecule of oxygen.

3.1.22

power density

ratio of power to the active electrode area of the cell/stack assembly unit electrodes

Note 1 to entry: Power density is calculated from the voltage multiplied by the current density ($P_d = V \times J$, where J is current density). It is expressed in $\text{W}\cdot\text{m}^{-2}$ or $\text{W}\cdot\text{cm}^{-2}$.

[SOURCE: IEC TS 62282-7-2:2014, 3.1.16, modified – Word "electrodes" added, and second sentence in the note to entry added.]

3.1.23

protection gas

mixture of hydrogen and inert gas (usually argon or nitrogen)

Note 1 to entry: It is often used to protect transition metal-containing negative electrodes of the SOC from being re-oxidized in the case of abnormal operating conditions (e.g. fuel interruption, emergency stop of the test station).

3.1.24

rated current

recommended continuous electric current as specified by the manufacturer, at which the SOC power system has been designed to operate

Note 1 to entry: The rated current is expressed in A.

[SOURCE: IEC 60050-485:—, 485-12-02, modified – Word "maximum" replaced by "recommended", and "fuel cell" replaced by "SOC".]

3.1.25

reactant gas

gas which is fed to the electrodes of the SOC where it reacts in an electrochemical reaction

Note 1 to entry: The reactant gases are the fuel and the oxidant in fuel cell mode and steam in electrolysis mode.

3.1.26

reversible mode

regenerative mode

operation mode of a solid oxide cell which alternates between fuel cell mode and electrolysis mode (Re-SOC)

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

3.1.27

repeating unit

RU

elementary unit which periodically repeats itself to form a stack

Note 1 to entry: For planar-geometry SOCs, it is composed of one single cell and two half interconnects on both sides of the single cell and usually also of a sealant to ensure gas-tightness and contact layers to minimize contact resistances between cells and interconnects.

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

3.1.28

solid oxide cell

SOC

electrochemical cell composed of three functional elements (negative electrode, electrolyte and positive electrode) based on ceramic oxide materials

Note 1 to entry: A SOC can consist of a single cell or of an assembly unit of multiple cells, called a stack.

Note 2 to entry: The two electrodes are made of electronic and possibly ionic conducting ceramics and are attached to one ionic conducting solid oxide ceramic electrolyte. Furthermore, the cell may contain a support layer which may be a ceramic

Note 3 to entry: SOCs can be used in fuel cell mode (SOFC) or in electrolysis mode (SOEC) with a layer or a non-ceramic layer as is the case for metal-supported cells.

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

3.1.29

solid oxide electrolysis cell

SOEC

SOC operated in electrolysis mode, i.e. reversed fuel cell mode

Note 1 to entry: Electricity is required as energy input. Where possible, heat may be used as additional energy input to reduce the amount of electrical work needed.

Note 2 to entry: It can be used to produce hydrogen from steam and, alternatively, to produce carbon monoxide from carbon dioxide, or syngas, a mixture of hydrogen and carbon monoxide from water vapour and carbon dioxide

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

3.1.30

solid oxide fuel cell

SOFC

SOC operated in fuel cell mode

Note 1 to entry: In this mode, it cogenerates electricity and heat using fuels such as hydrogen.

Note 2 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 voltage or output current of the unit to remain within its tolerance range of variation

[SOURCE: IEC TS 62282-7-2:2014, 3.1.9]

3.1.32

fuel cell stack

stack

assembly of cells, interconnectors, cooling plates, manifolds and a supporting structure that electrochemically converts, typically hydrogen-rich gas and air reactants to DC power, heat and other reaction products

Note 1 to entry: For planar geometry SOCs, the supporting structure consists of two endplates ("top plate" and "bottom plate") to facilitate applying a compression force to all RUs.

[SOURCE: IEC 60050-485:—, 485-06-01, modified – Word "separators" replaced by "interconnectors", and note to entry added.]

3.1.33

test input parameter

TIP

parameter 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 stay 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

parameter that indicates the response of the test system/test object as a result of variation of 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**theoretical current**

current when the supplied positive and negative electrode gases are completely consumed in electrochemical reactions divided by the number of cells in a series connection

Note 1 to entry: Theoretical current is expressed in A.

3.1.36**total impedance**

frequency-dependent losses due to ohmic, activation, diffusion, concentration effects, stray (parasitic) capacitance and inductances

Note 1 to entry: Total impedance is expressed in $\Omega \cdot \text{m}^2$ or $\Omega \cdot \text{cm}^2$.

[SOURCE: IEC TS 62282-7-2:2014, 3.1.17, modified – Words "stray (parasitic) capacitance and inductances" added, and note to entry added.]

3.1.37**total resistance**

real part of low-frequency limit of total impedance

Note 1 to entry: Total resistance is expressed in $\Omega \cdot \text{m}^2$ or $\Omega \cdot \text{cm}^2$.

[SOURCE: IEC TS 62282-7-2:2014, 3.1.18, modified – Removed reference to slope of I - V curve, and addition of note to entry.]

3.2 Abbreviated terms and symbols**3.2.1 Abbreviated terms**

BOP	balance of plant
EIS	electrochemical impedance spectroscopy
LHV	lower heating value
HHV	higher heating value
OCV	open circuit voltage
SOC	solid oxide cell
SOEC	solid oxide electrolysis cell
SOFC	solid oxide fuel cell
Re-SOC	regenerative solid oxide cell
RU	repeating unit
SPT	standard pressure and temperature
TIP	test input parameter
TOP	test output parameter

3.2.2 Symbols

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

Table 1 – Symbols

Symbol	Definition	Unit
A_{active}	Active (surface) area of the cell/stack electrode(s)	m ² , cm ²
c	Concentration	
c_i	Molar concentration of component i	mol/m ³
F	Faraday constant, force	
F	Faraday constant (96485,3)	C/mol
F_{comp}	Compression force applied onto the cell/stack	N
f	Frequency	
f	Excitation frequency	Hz
f_{char}	Characteristic frequency	Hz
I, J	Current, current density	
I_{cell}	Cell current	A
I_{n}	Nominal current	A
I_{stack}	Stack current	A
I_{RU}	Repeating unit current	A
$\underline{I}$	Fourier transform of excitation current	A
I_{pk}	Amplitude of alternating current	A
i	Excitation current (galvanostatic mode), current response (potentionstatic mode)	A
J	Current density	A/m ² , A/cm ²
J_{rr}	Current density ramp rate	A/(m ² ·s), A/(cm ² ·s)
$\mathbf{i}$	Imaginary unit	
N, n	Number of items	
N_{cycles}	Number of cycles	
N_{periods}	Number of measuring periods	
N_{points}	Number of measuring points	
n	Number of transferred electrons	
P	Power	
P_{el}	Electric power	W
P_{d}	Electric power density	W/m ² , W/cm ²
p	Pressure	
p_{vessel}	Pressure inside containment vessel	kPa
$p_{\text{neg,in}}$	Pressure of negative electrode gas at cell/stack inlet	kPa
$p_{\text{neg,out}}$	Pressure of negative electrode gas at cell/stack outlet	kPa
$p_{\text{pos,in}}$	Pressure of positive electrode gas at cell/stack inlet	kPa
$p_{\text{pos,out}}$	Pressure of positive electrode gas at cell/stack outlet	kPa
p_0	Standard pressure (101,325)	kPa
q_V	Volumetric flow rate	
$q_{V,\text{neg,in}}$	Total volumetric flow rate at negative electrode inlet (at STP)	m ³ /s, l/min
$q_{V,\text{pos,in}}$	Total volumetric flow rate at positive electrode inlet (at STP)	m ³ /s, l/min

Symbol	Definition	Unit
$q_{V,neg,out}$	Total volumetric flow rate at negative electrode outlet (at STP)	m ³ /s, l/min
$q_{V,pos,out}$	Total volumetric flow rate at positive electrode outlet (at STP)	m ³ /s, l/min
$q_{V,i,neg,in}$	Volumetric flow rate of gas component i at negative electrode inlet (at STP)	m ³ /s, l/min
$q_{V,i,pos,in}$	Volumetric flow rate of gas component i at positive electrode inlet (at STP)	m ³ /s, l/min
$q_{V,i,neg,out}$	Volumetric flow rate of gas component i at negative electrode outlet (at STP)	m ³ /s, l/min
$q_{V,i,pos,out}$	Volumetric flow rate of gas component i at positive electrode outlet (at STP)	m ³ /s, l/min
R	Resistance, universal gas constant	
R	Resistance	Ω
R_{ASR}	Area-specific resistance	$\Omega \cdot m^2$, $\Omega \cdot cm^2$
R_{LF}	Low frequency resistance	Ω
R_{HF}	High frequency resistance	Ω
R_{ohm}	Ohmic resistance	Ω
$R_{non-ohm}$	Non-ohmic resistance	Ω
R_g	Universal gas constant (8,3145)	J/(mol·K)
T	Temperature	
$T_{cell/stack}$	Temperature of the cell or stack	°C, K
$T_{stack,av}$	Average temperature of the stack	°C, K
$T_{stack,intern}$	Internal stack temperature	°C, K
T_{BP}	Temperature of bottom plate	°C, K
T_{TP}	Temperature of top plate	°C, K
$T_{furnace}$	Temperature of the furnace	°C, K
T_{min}	Minimum temperature during cycling	°C, K
$T_{neg,in}$	Temperature of negative electrode gas stream at cell/stack inlet	°C, K
$T_{pos,in}$	Temperature of positive electrode gas stream at cell/stack inlet	°C, K
$T_{neg,out}$	Temperature of negative electrode gas stream at cell/stack outlet	°C, K
$T_{pos,out}$	Temperature of positive electrode gas stream at cell/stack outlet	°C, K
$T_{PH,neg}$	Temperature of the pre-heater for preheating the negative electrode gas stream	°C, K
$T_{PH,pos}$	Temperature of the pre-heater for preheating the positive electrode gas stream	°C, K
T_0	Standard temperature (273,15)	K
ΔT_{max}	Maximum temperature difference between reactants and the stack temperature during start-up	K
t	Time	s, min, h
t_{acq}	Data acquisition time	s, min, h
t_{dwell}	Dwell time	s, min, h
t_{eq}	Equilibration time	s, min, h
t_{op}	Duration time of operation at given conditions	s, min, h
t_0	Initial time	
t_1	End time	

Symbol	Definition	Unit
U	Utilization	
$U_{\text{gas,neg}}$	Reactant utilization at the negative electrode (fuel utilization in fuel cell mode, steam conversion in electrolysis mode)	
$U_{\text{gas,pos}}$	Reactant utilization at the positive electrode (air utilization or oxygen utilization, valid only in fuel cell mode)	
V	Voltage	
V_{cell}	Voltage of the cell	V
V_{stack}	Voltage of the stack	V
$V_{\text{RU},i}$	Voltage of repeating unit (RU) i in the stack	V
$V_{\text{RU,av}}$	Average RU voltage of all RU in the stack	V
$\underline{V}$	Fourier transform of AC part of cell/stack voltage response	V
V_{pk}	Amplitude of alternating voltage	V
v	Excitation voltage (potentiostatic mode), voltage response (galvanostatic mode)	V
x	Fraction	
x_i	Molar fraction of component i	mol/mol
$x_{i,\text{neg,in}}$	Molar fraction of component i in the negative electrode gas stream inlet at cell/stack	mol/mol
$x_{i,\text{neg,out}}$	Molar fraction of component i in the negative electrode gas stream outlet at cell/stack	mol/mol
$x_{i,\text{pos,in}}$	Molar fraction of component i in the positive electrode gas stream inlet at cell/stack	mol/mol
$x_{i,\text{pos,out}}$	Molar fraction of component i in the positive electrode gas stream outlet at cell/stack	mol/mol
$x_{\text{H}_2\text{O}}$	Steam molar fraction	mol/mol
x_{O_2}	Oxygen molar fraction	mol/mol
$\underline{Y}, \underline{Z}$	Admittance, impedance	
$\underline{Y}$	Admittance	S
	Specific admittance	$\text{S}\cdot\text{m}^{-2}$, S cm^{-2}
$\underline{Y}'$	Real part of admittance (conductance)	S
	Real part of specific admittance	$\text{S}\cdot\text{m}^{-2}$, S cm^{-2}
$\underline{Y}''$	Imaginary part of admittance (susceptance)	S
	Imaginary part of specific admittance	$\text{S}\cdot\text{m}^{-2}$, S cm^{-2}
$\underline{Z}$	Impedance	Ω
	Specific impedance	$\Omega\cdot\text{cm}^2$, $\Omega\cdot\text{m}^2$
$ \underline{Z} $	Modulus of impedance	Ω
	Modulus of specific impedance	$\Omega\cdot\text{cm}^2$, $\Omega\cdot\text{m}^2$
$\underline{Z}'$	Real part of impedance (resistance)	Ω
	Real part of specific impedance	$\Omega\cdot\text{cm}^2$, $\Omega\cdot\text{m}^2$
$\underline{Z}''$	Imaginary part of impedance (reactance)	Ω
	Imaginary part of specific impedance	$\Omega\cdot\text{cm}^2$, $\Omega\cdot\text{m}^2$
$\Delta\alpha$	Degradation rate	
$\Delta\alpha_{\text{rel}}$	Relative degradation rate	
ω, φ	Angular frequency, phase angle	
ω	Angular perturbation frequency	

Symbol	Definition	Unit
$\omega_{\min}$	Minimum frequency for EIS spectra	rad/s
$\omega_{\max}$	Maximum frequency for EIS spectra	rad/s
φ	Phase angle	rad, °
NOTE 1 The standard temperature and pressure (STP) values for gas temperature and pressure are specified as follows: $T_0 = 273,15 \text{ K}$ $p_0 = 101,325 \text{ kPa}$ NOTE 2 To express the rate of change of a certain parameter x, a dot above the parameter symbol can be used. For instance, $\dot{T}$ can be used to express the temperature ramp with a unit of K/s, $\dot{q}_v$ used to express the speed of variation of the gas flow rate with a unit of (m³/s)/s. Alternatively, $(\Delta x/\Delta t)$ can be used. For instance, the temperature ramp can be expressed by $(\Delta T/\Delta t)$ and the speed of current density variation can be expressed by $(\Delta j/\Delta t)$. NOTE 3 About the amplitude of alternating current/voltage with a sine waveform for electrochemical impedance spectroscopy (EIS) measurement: it refers here to the peak amplitude. It amounts to half of the peak-to-peak amplitude and $\sqrt{2}$ times the root mean square (RMS) amplitude. NOTE 4 The real part of impedance (resistance) and imaginary part of impedance (reactance) can also be represented by $Re(Z)$ and $Im(Z)$, respectively. NOTE 5 The quantity $\Delta\alpha$ chosen for calculating the degradation rate can be the cell or stack voltage, current, power density or ASR, each with their own unit.		

3.3 Flow rates

In this document, volumetric flow rates are used, following common practice. Volumetric flow rate can however be replaced in principle by mass flow rate, taking into consideration the molar mass and density of the species considered.

4 General safety conditions

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

The solid oxide cell/stack in particular operates at high temperatures, typically above 600 °C, which are higher than the spontaneous ignition temperatures of both hydrogen (565 °C) and methane (537 °C). Those who carry out cell/stack assembly unit testing shall be trained and experienced in the operation of test systems and specifically in safety procedures involving electrical equipment, hot surfaces and fluids (e.g. steam), and (reactive) compressed gases handling.

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.

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, hydrocarbons and carbon monoxide, shall be followed.

In summary, safely operating a test station requires appropriate technical training and experience as well as safe facilities and equipment, all of which are outside the scope of this document.