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Part 3-200: Stationary fuel cell power systems - Performance test methods

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

PROJECT NUMBER: IEC 62282-3-200 ED3	
DATE OF CIRCULATION: 2023-02-24	CLOSING DATE FOR COMMENTS: 2023-05-19
SUPERSEDES DOCUMENTS: 105/917/RR	

IEC TC 105 : FUEL CELL TECHNOLOGIES	
SECRETARIAT: Germany	SECRETARY: Mr David Urmann
OF INTEREST TO THE FOLLOWING COMMITTEES:	PROPOSED HORIZONTAL STANDARD: ☐ Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.
FUNCTIONS CONCERNED: ☐ EMC ☐ ENVIRONMENT ☐ QUALITY ASSURANCE ☐ SAFETY	

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- any relevant patent rights of which they are aware and to provide supporting documentation,
- any local regulations or technical reasons that may exist and should be considered should this proposal proceed, recognizing that failure to address such requirements could result in the need for new or existing "in some countries" clauses. See AC/22/2007.

TITLE:

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

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FUEL CELL TECHNOLOGIES –

Part 3-200: Stationary fuel cell power systems –
Performance test methods

FOREWORD

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IEC 62282-3-200 has been prepared by IEC technical committee 105: Fuel cell technologies. It is an International Standard.

This **third** edition cancels and replaces the **second** edition of IEC 62282-3-200 published in 2015. This edition constitutes a technical revision.

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

- a) ...;
- b)

IEC has published a related but independent standard IEC 62282-3-201 on performance test methods of small stationary fuel cell power systems which is harmonized with this standard.

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

Draft	Report on voting
XX/XX/FDIS	XX/XX/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.

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

INTRODUCTION

This part of IEC 62282 describes how to measure the performance of stationary fuel cell power systems for residential, commercial, agricultural and industrial applications.

This standard describes type tests and their test methods only. In this standard, no routine tests are required or identified, and no performance targets are set.

This document applies to all kinds of stationary fuel cell technologies, such as:

- alkaline fuel cells (AFC);
- phosphoric acid fuel cells (PAFC);
- polymer electrolyte fuel cells (PEFC);
- molten carbonate fuel cells (MCFC);
- solid oxide fuel cells (SOFC).

FUEL CELL TECHNOLOGIES –

Part 3-200: Stationary fuel cell power systems – Performance test methods

1 Scope

This part of IEC 62282 covers operational and environmental aspects of the stationary fuel cell power systems performance. The test methods apply as follows:

- power output under specified operating and transient conditions;
- electrical and heat recovery efficiency under specified operating conditions;
- environmental characteristics; for example, exhaust gas emissions, noise, etc. under specified operating and transient conditions.

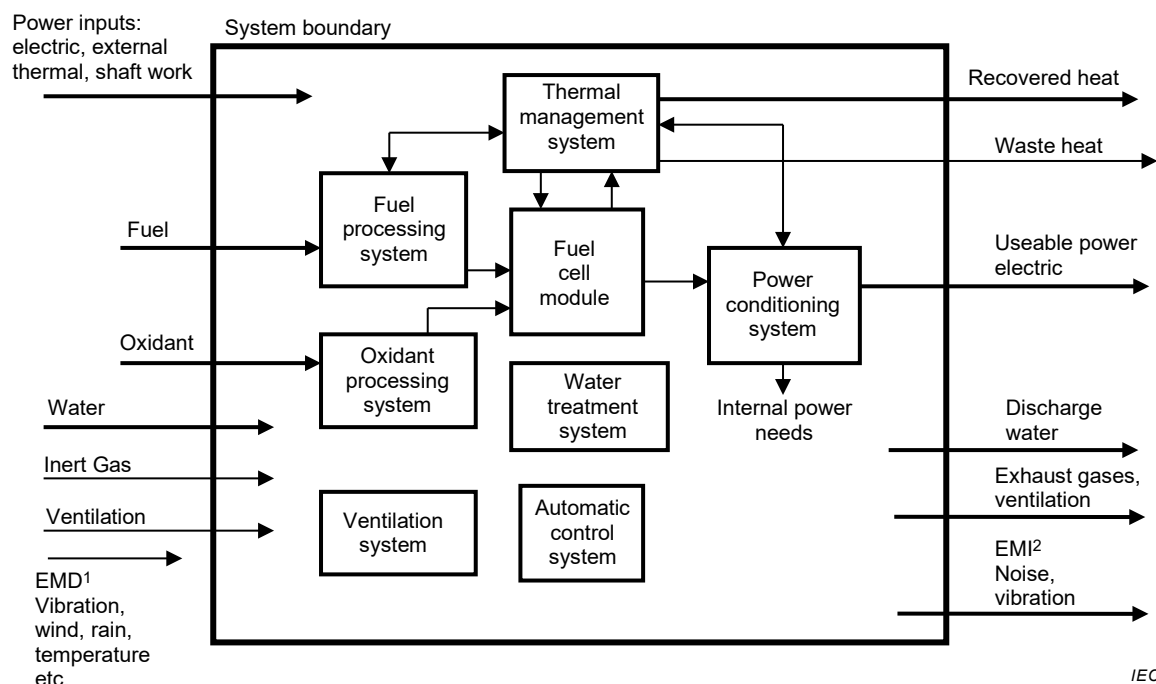
This standard does not provide coverage for electromagnetic compatibility (EMC).

This standard does not apply to small stationary fuel cell power systems with rated electric power output of less than 10 kW which are dealt with IEC 62282-3-201.

Fuel cell power systems may have different subsystems depending upon types of fuel cell and applications, and they have different streams of material and energy into and out of them. However, a common system diagram and boundary has been defined for evaluation of the fuel cell power system (see Figure 1).

The following conditions are considered in order to determine the system boundary of the fuel cell power system:

- all energy recovery systems are included within the system boundary;
- all kinds of electric energy storage devices are considered outside the system boundary;
- calculation of the heating value of the input fuel (such as natural gas, propane gas and pure hydrogen gas, etc.) is based on the conditions of the fuel at the boundary of the fuel cell power system.



Key



Fuel cell power system including subsystems. The interface is defined as a conceptual or functional one instead of hardware such as a power package.



Subsystems; fuel cell module, fuel processor, etc. These subsystem configurations depend on the kind of fuel, type of fuel cell or system.



The interface points in the boundary to be measured for calculation data.

¹ EMD electromagnetic disturbance

² EMI electromagnetic interference

Figure 1 – Fuel cell power system diagram

2 Normative references

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

IEC 60051 (all parts), *Direct acting indicating analogue electrical measuring instruments and their accessories*

IEC 60359, *Electrical and electronic measurement equipment – Expression of performance*

IEC 60688, *Electrical measuring transducers for converting A.C. and D.C. electrical quantities to analogue or digital signals*

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*

- 61 IEC 61028, *Electrical measuring instruments – X-Y recorders*
- 62 IEC 61143 (all parts), *Electrical measuring instruments – X-t recorders*
- 63 IEC 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*
- 64 IEC 61672-2, *Electroacoustics – Sound level meters – Part 2: Pattern evaluation tests*
- 65 IEC 62052-11, *Electricity metering equipment (AC) – General requirements, tests and test*
66 *conditions – Part 11: Metering equipment*
- 67 IEC 62053-22, *Electricity metering equipment (a.c.) – Particular requirements – Part 22: Static*
68 *meters for active energy (classes 0,2 S and 0,5 S)*
- 69 IEC 62282-3-201, *Fuel cell technologies – Part 3-201: Stationary fuel cell power systems –*
70 *Performance test methods for small fuel cell power systems*
- 71 ISO 3648, *Aviation fuels – Estimation of net specific energy*
- 72 ISO 3744, *Acoustics – Determination of sound power levels and sound energy levels of noise*
73 *sources using sound pressure – Engineering methods for an essentially free field over a*
74 *reflecting plane*
- 75 ISO 4677-1, *Atmospheres for conditioning and testing – Determination of relative humidity –*
76 *Part 1: Aspirated psychrometer method*
- 77 ISO 4677-2, *Atmospheres for conditioning and testing – Determination of relative humidity –*
78 *Part 2: Whirling psychrometer method*
- 79 ISO 5167 (all parts), *Measurement of fluid flow by means of pressure differential devices*
80 *inserted in circular cross-section conduits running full*
- 81 ISO 5348, *Mechanical vibration and shock – Mechanical mounting of accelerometers*
- 82 ISO 5815-2, *Water quality – Determination of biochemical oxygen demand after n days (BOD_n)*
83 *– Part 2: Method for undiluted samples*
- 84 ISO 6060, *Water quality – Determination of the chemical oxygen demand*
- 85 ISO 6326 (all parts), *Natural gas – Determination of sulfur compounds*
- 86 ISO 6974 (all parts), *Natural gas – Determination of composition and associated uncertainty by*
87 *gas chromatography*
- 88 ISO 6975 (all parts), *Natural gas – Extended analysis – Gas chromatographic method*
- 89 ISO 7934, *Stationary source emissions – Determination of the mass concentration of sulfur*
90 *dioxide – Hydrogen peroxide/barium perchlorate/Thorin method*
- 91 ISO 7935, *Stationary source emissions – Determination of the mass concentration of sulfur*
92 *dioxide – Performance characteristics of automated measuring methods*
- 93 ISO 8217, *Petroleum products – Fuel (class F) – Specifications of marine fuels*
- 94 ISO 10101 (all parts), *Natural gas – Determination of water by the Karl Fisher method*

- 95 ISO 10396, *Stationary source emissions – Sampling for the automated determination of gas*
96 *emission concentrations for permanently installed monitoring systems*
- 97 ISO 10523, *Water quality – Determination of pH*
- 98 ISO 10849, *Stationary source emissions – Determination of the mass concentration of nitrogen*
99 *oxides – Performance characteristics of automated measuring systems*
- 100 ISO 11042-1, *Gas turbines – Exhaust gas emission – Part 1: Measurement and evaluation*
- 101 ISO 11042-2, *Gas turbines – Exhaust gas emission – Part 2: Automated emission monitoring*
- 102 ISO 11541, *Natural gas – Determination of water content at high pressure*
- 103 ISO 11564, *Stationary source emissions – Determination of the mass concentration of nitrogen*
104 *oxides – Naphthylethylenediamine photometric method*
- 105 ISO 11632, *Stationary source emissions – Determination of mass concentration of sulfur*
106 *dioxide – Ion chromatography method*
- 107 ISO 14687-1, *Hydrogen fuel – Product specification – Part 1: All applications except proton*
108 *exchange membrane (PEM) fuel cell for road vehicles*
- 109 ISO/TR 15916, *Basic consideration for the safety of hydrogen systems*
- 110 ISO 16622, *Meteorology – Sonic anemometers/thermometers – Acceptance test methods for*
111 *mean wind measurements*
- 112 ASTM D4809, *Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by*
113 *Bomb Calorimeter (Precision Method)*
- 114 ASTM F2602, *Standard Test Method for Determining the Molar Mass of Chitosan and Chitosan*
115 *Salts by Size Exclusion Chromatography with Multi-angle Light Scattering Detection (SEC-*
116 *MALS)*

117 **3 Terms, definitions, operating process and symbols**

118 **3.1 Terms and definitions**

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

120 **3.1.1**

121 **auxiliary electric power input**

122 electric power for auxiliary machines and equipment supplied from outside the system boundary

123 **3.1.2**

124 **background noise level**

125 sound pressure level of ambient noise at the measurement point

126 Note 1 to entry: This measurement is taken as described in this standard with the fuel cell power system in the cold
127 state.

128 **3.1.3**

129 **background vibration level**

130 mechanical oscillations caused by the environment that affect vibration level readings

Note 1 to entry: In this standard, background vibration is measured with the fuel cell power system in the cold state.

3.1.4

cold state

state of a fuel cell power system, which is entirely at ambient temperature with no power input or output, ready for start-up.

Note 1 to entry: Power input to a control device for monitoring the fuel cell power system during cold state is not considered.

[SOURCE: IEC 60050-485:2020, 485-21-01, modified — “which is entirely” and “ready for start-up” added; Note 1 to entry added.]

3.1.5

discharge water

water discharged from the fuel cell power system including waste water and condensate

3.1.6

electrical efficiency

ratio of the average net electric power output produced by a fuel cell power system to the average total power input supplied to the fuel cell power system

Note 1 to entry: Lower heating value (LHV) is assumed unless otherwise stated.

Note 2 to entry: Any electric power that is supplied to auxiliary machines and equipment of a fuel cell power system from an external source is deducted from the electric power output of the fuel cell power system.

[SOURCE: IEC 60050-485:2020, 485-10-02, modified – “electrical” instead of “electric” in the term; “average net electric power output” instead of “net electric power”; “average total power input” instead of “total enthalpy flow”; Note 2 to entry” added]

3.1.7

external thermal energy

additional thermal energy input from outside the system boundary

Note 1 to entry: External thermal energy can be supplied e.g. by make-up water or process condensate return.

3.1.8

fuel cell module

assembly incorporating one or more fuel cell stacks and, if applicable, additional components, that is intended to be integrated into a power system

Note 1 to entry: A fuel cell module comprises the following main components: one or more fuel cell stack(s), a piping system for conveying fuels, oxidants and exhausts, electric connections for the power delivered by the stack(s), and means for monitoring, control or both. Additionally, a fuel cell module can comprise: means for conveying additional fluids (e.g. cooling media, inert gas), means for detecting normal and abnormal operating conditions, enclosures or pressure vessels and module ventilation systems, and the required electronic components for module operation and power conditioning.

[SOURCE: IEC 60050-485:2020, 485-09-03, modified – “or a vehicle” deleted]

3.1.9

fuel cell power system

generator system that uses one or more fuel cell modules to generate electric power and heat

Note 1 to entry: A fuel cell power system is composed of all or some of the systems shown in Figure 1.

[SOURCE: IEC 60050-485:2020, 485-09-01, modified – “Note 1 to entry” added]

3.1.10**fuel input**

amount of natural gas, hydrogen, methanol, liquid petroleum gas, propane, butane, or other substance containing chemical energy introduced to the fuel cell power system during specified operating conditions

3.1.11**heat recovery efficiency**

ratio of the average recovered thermal power output of a fuel cell power system to the average total power input supplied to the fuel cell power system

[SOURCE: IEC 60050-485:2020, 485-10-04, , modified – “average recovered thermal power output” instead of “recovered heat flow”; “average total power input” instead of “total enthalpy flow”; “Note 1 to entry” deleted]

3.1.12**interface point**

measurement point at the boundary of a fuel cell power system at which material or energy, or both, either enters or leaves

Note 1 to entry: This boundary is intentionally selected to accurately measure the performance of the system including all normal operation, both steady state and transient. If necessary, the boundary or the interface points of the fuel cell power system (Figure 1) to be assessed should be determined by agreement between the parties.

[SOURCE: IEC 60050-485:2020, 485-09-12, modified — Note 2 to entry deleted.]

3.1.13**minimum power**

lowest net electric power output at which a fuel cell power system is able to operate continuously in a stable manner

[SOURCE: IEC 60050-485:2020, 485-13-02, modified – “output” added, “Note 1 to entry” deleted]

3.1.14**noise level**

sound pressure level produced by a fuel cell power system

Note 1 to entry: Expressed in decibels (dB) and measured at a specified distance and in all operation modes as described in this standard.

3.1.15**operating temperature**

temperature at which fuel cell power system operates and is specified with a measuring point by the manufacturer

3.1.16**overall energy efficiency**

ratio of total useable power output (net electrical power and recovered thermal power) to the average total power input supplied to the fuel cell power system

Note 1 to entry: The supplied total power input of the fuel should be related to the lower heating value (LHV) for a better comparison with other types of energy conversion systems.

Note 2 to entry: Refer to 4.3 regarding reporting based on LHV or HHV.

[SOURCE: IEC 60050-485:2020, 485-10-05, modified – alternative expression “or total thermal efficiency” deleted; “power output” instead of “energy flow”; “thermal power” instead of “heat flow”; “average total power input” instead of “total enthalpy flow”; “Note 2 to entry” added]

3.1.17**oxidant input**

amount of oxidant (air) input into the inside of the fuel cell module during specified operating conditions

Note 1 to entry: The oxidant is usually air, but other oxidants (e.g., oxygen) can be used.

3.1.18**power response time**

duration between the instant of initiating a change of electric or thermal power output and when the electric or thermal power output attains the set value within tolerance

3.1.19**90 % power response time**

duration between the instant of initiating a change of electric or thermal power output and when the electric or thermal power output attains 90 % of the desired value

3.1.20**pre-generation state**

state of a fuel cell power system at sufficient operating temperature and in such an operational mode, with zero electric power output, that the fuel cell power system is capable of being promptly switched to an operational state with a substantial electric or thermal active power output

[SOURCE: IEC 60050-485:2020, 485-21-04, modified – “or thermal active” added]

3.1.21**purge gas consumption**

amount of inert gas or dilution gas supplied to the fuel cell power system during specific conditions to make it ready for operation or shutdown

3.1.22**net electric power output**

power generated by the fuel cell power system and available for external use

[SOURCE: IEC 60050-485:2020, 485-14-03, modified — “output” added to the term, Notes 1 and 2 to entry deleted.]

3.1.23**rated power**

maximum continuous electric power output that a fuel cell power system is designed to achieve under normal operating conditions specified by the manufacturer

[SOURCE: IEC 60050-485:2020, 485-14-04, modified – “Note 1 to entry” deleted]

3.1.24**recovered heat**

thermal energy that has been recovered for useful purposes

Note 1 to entry: The recovered heat is measured by determining the temperatures and flow rates of heat recovery fluid (water, steam, air or oil, etc.), entering and leaving the thermal energy recovery subsystem at the interface point of the fuel cell power system.

3.1.25**reference condition**

values of influence quantities prescribed for testing the performance of a measuring instrument, which in this document are 288,15 K (15 °C) for temperature and 101,325 kPa for pressure

3.1.26**response time to rated power**

duration between the instant when the step load change to rated power is initiated and the first instant when this value is delivered within a tolerance value

3.1.27**shaft work**

mechanical energy input from outside the system boundary for accomplishing useful work

3.1.28**shutdown time**

duration between the instant when a shutdown action is initiated at rated electric power output and the instant when the shutdown is completed, as specified by the manufacturer

Note 1 to entry: The shutdown operation is classified into types: normal shutdown and emergency shutdown.

[SOURCE: IEC 60050-485:2020, 485-20-04, modified – “a shutdown action is initiated at rated power” instead of “the load is removed”; “Note 1 to entry” added]

3.1.29**start-up energy**

sum of the electric, thermal, mechanical and chemical (fuel) energy required by a fuel cell power system during the start-up time

[SOURCE: IEC 60050-485:2020, 485-18-05]

3.1.30**start-up time**

a) for fuel cell power systems that do not require external energy to maintain a storage state, duration required for transitioning from cold state to positive net electrical power output; and

b) for fuel cell power systems that require external power to maintain a storage state, duration required for transitioning from storage state to positive net electrical power output

[SOURCE: IEC 60050-485:2020, 485-20-05 and 485-20-06, modified – “positive” added]

3.1.31**storage state**

state of a fuel cell power system being non-operational and possibly requiring, under conditions specified by the manufacturer, the input of thermal energy, electric energy or an inert atmosphere, or any combination thereof, in order to prevent deterioration of the components and/or to energize the control systems

[SOURCE: IEC 60060-485:2020, 485-21-06, modified – “and/or to energize the control system” added]

3.1.32**test run**

testing phase in which data points required for the computation of test results are recorded

3.1.33**total power input**

total consisting of fuel power input, oxidant (air) power input, auxiliary electric power input, shaft work power input and external thermal power input

3.1.34**vibration level**

measurement value of mechanical oscillations produced by the fuel cell power system during operation

Note 1 to entry: This is a value expressed in decibels (dB) as described in this standard.

3.1.35**waste heat**

thermal energy output released and not recovered

3.1.36**waste water**

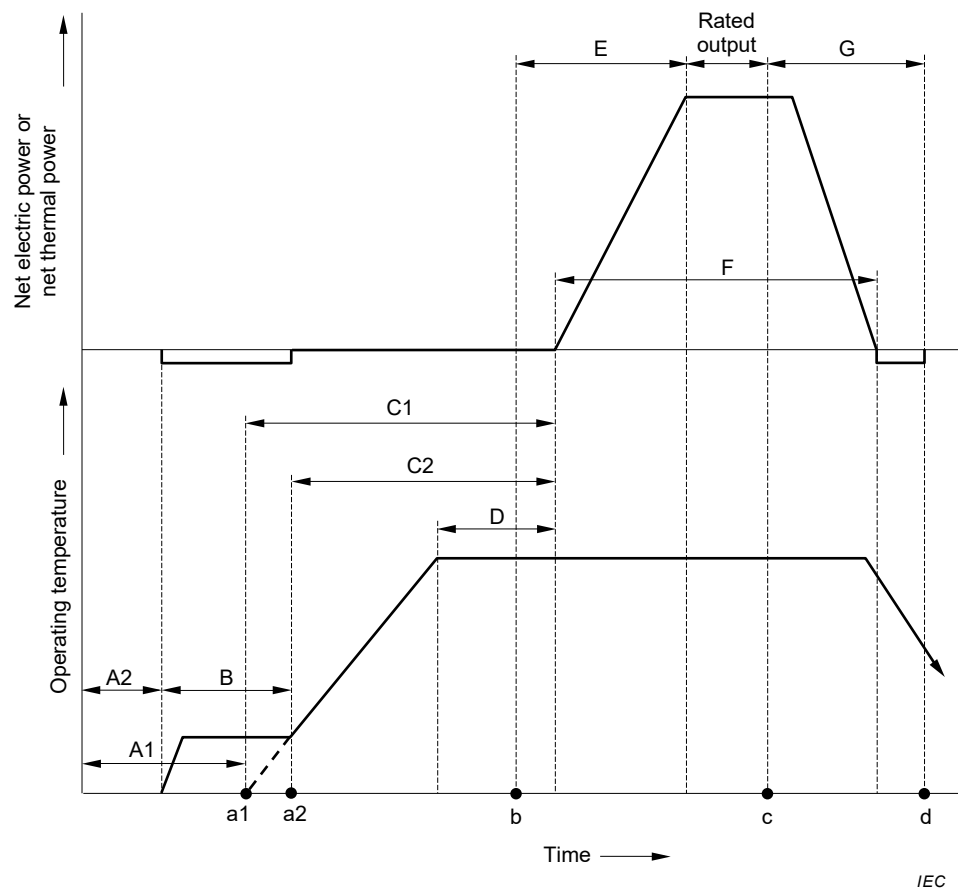
excess water that is removed from the fuel cell power system and that does not constitute part of the thermal recovery system

3.1.37**water consumption**

water supplied from outside the system boundary to the fuel cell power system other than initial fill

3.2 Operating process

Figure 2 provides the typical operating states of a stationary fuel cell power system. The figure shows a chronological series of changes in the operating state from start-up, to generation, to shutdown, and provides definitions for the terms corresponding to the different operating states.



- Key**
- A1 Cold state (if storage state is not required)
 - A2 Cold state (if storage state is required)
 - B Storage state (example of storage state requiring thermal and/or electric energy input)
 - C1 Start-up time for systems that require no external energy to maintain storage state (measured from cold state)
 - C2 Start-up time for systems that require external energy to maintain storage state (measured from storage state)
 - D Pre-generation state
 - E Response time to rated electric power output
 - F Generation state
 - G Shutdown time
 - a1 Time when start-up action is initiated (from cold state)
 - a2 Time when start-up action is initiated (from storage state)
 - b Time when output action is initiated
 - c Time when shutdown action is initiated
 - d Time when shutdown action is completed (shutdown completion conditions as specified by the manufacturer)
 - a1 or a2 to d Operational mode (from the initiation of start-up to the completion of shutdown)

Figure 2 – Operating process chart of fuel cell power system

3.3 Symbols

The symbols and their meanings used in this part of IEC 62282 are given in Table 1, with the appropriate units.

Table 1 – Symbols

Symbol	Definition	Unit
c	Specific heat capacity	
c_{HR}	Specific heat capacity of heat recovery fluid	kJ/(kg·K)
c_j	Specific heat capacity of pure component j	kJ/(kg·K)
E	Energy	
E_{st}	Start-up energy	kJ
E_{elst}	Electric start-up energy	kJ
E_{fst}	Fuel start-up energy	kJ
E_{ast}	Oxidant (air) start-up energy	kJ
E_{Vf}	Energy input of the fuel per unit volume	kJ/m ³
E_{mf}	Energy input of fuel per mole, as given in worksheet 1 of Annex B	kJ/mol
E_{mpf}	Pressure energy of the fuel per mole at average pressure p_f	kJ/mol
E_{ma}	Energy input of oxidant (air) per mole	kJ/mol
E_{mpa}	Pressure energy of oxidant (air) per mole	kJ/mol
H	Heating value	
H_{f0}	Heating value of gaseous fuel under reference conditions	kJ/mol
H_{f0j}	Heating value of component j at reference temperature T_0	kJ/mol
H_{fl}	Heating value of liquid fuel at average temperature T_f	kJ/kg
H_{m}	Molar enthalpy	
H_{mf}	Molar enthalpy of fuel at average temperature T_f	kJ/mol
H_{ma}	Molar enthalpy of oxidant (air) at average temperature T_a	kJ/mol
H_{mf0}	Molar enthalpy of fuel at reference temperature T_0	kJ/mol
H_{ma0}	Molar enthalpy of oxidant (air) at reference temperature T_0	kJ/mol
H_{mfj}	Molar enthalpy of component j at average temperature T_f	kJ/mol
h_{m}	Specific enthalpy	
h_{min}	Average specific enthalpy of heat transfer fluid (steam, air, etc.) entering the fuel cell power system over the test duration	kJ/kg
h_{mout}	Average specific enthalpy of heat transfer fluid (steam, air, etc.) exiting the fuel cell power system over the test duration	kJ/kg
h_{mwsat0}	Specific enthalpy of saturated water at reference temperature T_0	kJ/kg
h_{mair0}	Specific enthalpy of dry air at reference pressure p_0 and reference temperature T_0	kJ/kg
M_{m}	Molar mass	
M_{ma}	Molar mass of oxidant (air)	kg/mol
M_{mf}	Molar mass of fuel	kg/mol
m	Mass	
m_{htf}	Mass of heat transfer fluid (steam, air, etc.) into (and out of) the fuel cell power system from the source of external thermal energy over the test duration	kg
P	Power	
P_{elout}	Average electric power output (including direct current)	kW
P_{elin}	Average auxiliary electric power input to auxiliary machines and equipment from external power source(s) (including direct current)	kW

Symbol	Definition	Unit
P_n	Average net electric power output	kW
$P_{\min}$	Minimum net electric power output	kW
P_{rated}	Rated net electric power output	kW
P_{in}	Average total power input	kJ/s
P_{fin}	Average gaseous or liquid fuel power input	kJ/s
P_{ain}	Average oxidant (air) power input	kJ/s
P_{wsin}	Average mechanical shaft work power input	kJ/s
P_{HR}	Average recovered thermal power output over the test duration	kJ/s
P_{thin}	Average external thermal power input	kJ/s
p	Pressure	
p_0	Reference pressure	kPa
p_f	Average pressure of fuel over the test duration	kPa
p_a	Average pressure of oxidant (air) over the test duration	kPa
Q	Thermal energy	
Q_{HR}	Recovered thermal energy over the test duration	kJ
Q_{thin}	Total external thermal energy input to the fuel cell power system over the test duration	kJ
Q_{thst}	Thermal start-up energy	kJ
q_m	Mass flow rate	
q_{mw}	Water consumption	kg/s
q_{mf}	Average mass flow rate of fuel	kg/s
q_{ma}	Average mass flow rate of oxidant (air)	kg/s
q_{mHR}	Mass flow rate of heat recovery fluid	kg/s
q_v	Volumetric flow rate	
q_{Vf0}	Average volumetric flow rate of fuel under reference conditions	m ³ /s
q_{Va0}	Average volumetric flow rate of oxidant (air) under reference conditions	m ³ /s
q_{Vf}	Average volumetric flow rate of fuel at average temperature T_f and average pressure p_f	m ³ /s
q_{Va}	Average volumetric flow rate of oxidant (air) at average temperature T_a and average pressure p_a	m ³ /s
q_{Vpg}	Purge gas flow rate	m ³ /s
q_{VHR}	Volumetric flow rate of heat recovery fluid	m ³ /s
T	Temperature	
T_0	Reference temperature	K
T_f	Average temperature of fuel over the test duration	K
T_a	Average temperature of oxidant (air) over the test duration	K
T_{HR1}	Temperature of heat recovery fluid output	K
T_{HR2}	Temperature of heat recovery fluid input	K
t	Time	
Δt_{st}	Start-up time	

Symbol	Definition	Unit
t_{st1}	Start-up initiation time point	
t_{st2}	Start-up completion time point	
Δt_{shut}	Shutdown time	s
t_{shut1}	Shutdown initiation time point	
t_{shut2}	Shutdown completion time point	
t_{up}	Response time required from t_{ini} to $t_{attain-rated}$	s
t_{down}	Response time required from t_{in} to $t_{attain-min}$	s
$t_{attain-rated}$	Time for the fuel cell power system to attain rated net electric or thermal power output within $\pm 2\%$ of rated power	
$t_{attain-min}$	Time for the fuel cell power system to attain minimum net electric or thermal power output within $\pm 2\%$ of rated power	
t_{ini}	Time when a net electric or thermal power output change is initiated by the user	
t_{dur}	Measurement duration	s
V_m	Molar volume	
V_{m0}	Reference molar volume of ideal gas ($2,364 \times 10^{-2} \text{ m}^3/\text{mol}$) (at reference temperature; 101,325 kPa: $t_0 = 288,15 \text{ K}$)	m^3/mol
W_s	Shaft work	
W_{sin}	Total shaft work	kJ
W_{sst}	Shaft work start-up energy	kJ
x	Mass fraction	
x_j	Mass fraction of component j	
η	Efficiency	
η_{el}	Electrical efficiency	%
η_{th}	Heat recovery efficiency	%
η_{total}	Overall energy efficiency	%
λ	Power factor	
λ	Power factor, the ratio of the effective power to the apparent power	
ρ	Density	
ρ_{f0}	Density of fuel under reference conditions	kg/m^3
ρ_{fl}	Density of liquid fuel at average temperature T_f	kg/m^3
ρ_{a0}	Density of oxidant (air) under reference conditions	kg/m^3
ρ_{HR}	Heat recovery fluid density at measured pressure and temperature	kg/m^3
Φ	Heat rate	
Φ_{WH}	Average waste heat rate	kJ/s
NOTE The main symbols in the fuel cell power system correspond to those in Figure 3.		

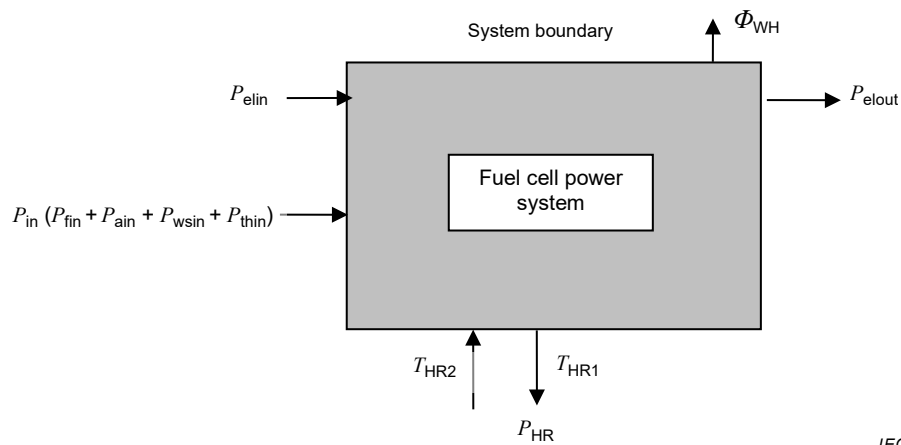


Figure 3 – Symbol diagram

4 Reference conditions

4.1 General

Clause 4 provides the reference conditions for the computation of the test results.

4.2 Temperature and pressure

The reference conditions are specified as follows:

- reference temperature: $T_0 = 288,15 \text{ K}$ (15 °C);
- reference pressure: $p_0 = 101,325 \text{ kPa}$.

4.3 Heating value base

The heating value of fuel is based on the lower heating value (LHV) in principle. Energy efficiency is expressed as follows:

$$\eta_{el} \text{ or } \eta_{th}; \text{ percent in value (\%)}$$

In the case of LHV, it is not necessary to add the symbol "LHV".

If the higher heating value (HHV) is applied, the abbreviation "HHV" shall be added to the value of energy efficiency as follows:

$$\eta_{el} \text{ or } \eta_{th}; \text{ percent in value (\%) (HHV)}$$

5 Item of performance test

The performance assessment of the fuel cell power systems shall be considered from the following points of view:

- a) operation aspects: to test the performance of the system during normal operation or during an operational transient;
- b) environmental aspects: to test how the system affects the environment.

Table 2 indicates the test items for the operating performance tests and the environmental performance tests. The test items in Table 2 shall be applied to the fuel cell power system considered as a whole.

Unless otherwise specified, all tests are required for all fuel cell types. Differences in system design and differences in technology may result in some portions of the tests being omitted (for example, systems without heat recovery will not require measurement of heat recovered).

Table 2 – Test classification and test item

Test	
Operational aspects	Environmental aspects
Efficiency test	Exhaust gas emission test
Electric power/thermal power response characteristics test	Noise level test
Start-up/shutdown characteristics test	Vibration level test
Purge gas consumption test	Discharge water quality test
Water consumption test	

6 Test preparation

6.1 General

Clause 6 describes typical items that shall be considered prior to the implementation of a test. For each test, an effort shall be made to minimize uncertainty by selecting high-precision instruments and planning the tests carefully with attention to detail. Detailed test plans shall be prepared by the parties to the test using this standard as the basis. A written test plan shall be prepared. Relevant test items are listed in Table 3.

The following shall be considered for the test plan:

- a) objective;
- b) test specifications;
- c) test personnel qualifications;
- d) quality assurance standards;
- e) target uncertainty (refer to Clauses A.1 and A.2);
- f) identification of measurement instruments (refer to Clause 7);
- g) estimated range of test parameters;
- h) data acquisition plan (refer to 6.2.2);
- i) where applicable, refer to ISO/TR 15916 or equivalent standard regarding the basic safety considerations for the use of hydrogen as fuel (as indicated in the documentation provided by the end-product manufacturer).

6.2 Uncertainty analysis

6.2.1 Uncertainty analysis items

An uncertainty analysis should be performed on the four test items below to indicate the reliability of the test results and to comply with customer requests. The following test results should be analysed to determine the absolute and relative uncertainty. A test should be planned so that the reliability of the results can be evaluated for the following items:

- electric power output;