



BSI Standards Publication

## Fuel cell technologies

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Part 3-201: Stationary fuel cell power systems — Performance test methods for small fuel cell power systems

## National foreword

This British Standard is the UK implementation of EN 62282-3-201:2017+A1:2022. It is identical to IEC 62282-3-201:2017, incorporating amendment 1:2022. It supersedes BS EN 62282-3-201:2017, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by **A1** **A1**.

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 committee manager.

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English Version

Fuel cell technologies - Part 3-201: Stationary fuel cell power  
systems - Performance test methods for small fuel cell power  
systems  
(IEC 62282-3-201:2017/AMD1:2022)

Technologies des piles à combustible - Partie 3-201:  
Systèmes à piles à combustible stationnaires - Méthodes  
d'essai des performances pour petits systèmes à piles à  
combustible  
(IEC 62282-3-201:2017/AMD1:2022)

Brennstoffzellentechnologien - Teil 3-201: Stationäre  
Brennstoffzellen-Energiesysteme -  
Leistungskennwertprüfverfahren für kleine  
Brennstoffzellen-Energiesysteme  
(IEC 62282-3-201:2017/AMD1:2022)

This amendment A1 modifies the European Standard EN 62282-3-201:2017; it was approved by CENELEC on 2022-03-10. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this amendment the status of a national standard without any alteration.

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Comité Européen de Normalisation Electrotechnique  
Europäisches Komitee für Elektrotechnische Normung

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## **European foreword**

The text of document 105/839/CDV, future IEC 62282-3-201/AMD1, prepared by IEC/TC 105 "Fuel cell technologies" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62282-3-201:2017/A1:2022.

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) 2022-12-10
- latest date by which the national standards conflicting with the document have to be withdrawn (dow) 2025-03-10

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The text of the International Standard IEC 62282-3-201:2017/AMD1:2022 was approved by CENELEC as a European Standard without any modification.

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## INTERNATIONAL ELECTROTECHNICAL COMMISSION

## FUEL CELL TECHNOLOGIES –

**Part 3-201: Stationary fuel cell power systems –  
Performance test methods for small fuel cell power systems**

## FOREWORD

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International Standard IEC 62282-3-201 has been prepared by IEC technical committee 105: Fuel cell technologies.

This second edition cancels and replaces the first edition published in 2013. This edition constitutes a technical revision.

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

- a) Revision of definitions
- b) Revision of symbols (Clause 4, in accordance with ISO/IEC 80000 series and ISO/IEC Directives Part 2);
- c) Revision of Figures 2, 5 and 6;
- d) Revision of test set-up (Clause 9);

- e) Revision of measurement instruments (Clause 10);
- f) Introduction of ramp-up test (14.6);
- g) Introduction of rated operation cycle efficiency (14.11);
- h) Introduction of electromagnetic compatibility (EMC) test (14.12);
- i) Revision of exhaust gas test (15.3);
- j) Introduction of typical durations of operation cycles (Annex F).

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

| CDV         | Report on voting |
|-------------|------------------|
| 105/564/CDV | 105/623/RVC      |

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 part of IEC 62282 provides consistent and repeatable test methods for the electrical, thermal and environmental performance of small stationary fuel cell power systems.

This document limits its scope to small stationary fuel cell power systems (electrical power output below 10 kW) and provides test methods specifically designed for them in detail. It is based on IEC 62282-3-200, which generally describes performance test methods that are common to all types of fuel cells.

This document is intended for manufacturers of small stationary fuel cell power systems and/or those who evaluate the performance of their systems for certification purposes.

Users of this document may selectively execute test items that are suitable for their purposes from those described in this document. This document is not intended to exclude any other methods.

## FUEL CELL TECHNOLOGIES –

### Part 3-201: Stationary fuel cell power systems – Performance test methods for small fuel cell power systems

#### 1 Scope

This part of IEC 62282 provides test methods for the electrical, thermal and environmental performance of small stationary fuel cell power systems that meet the following criteria:

- output: rated electric power output of less than 10 kW;
- output mode: grid-connected/independent operation or stand-alone operation with single-phase AC output or 3-phase AC output not exceeding 1 000 V, or DC output not exceeding 1 500 V;

NOTE The limit of 1 000 V for alternating current comes from the definition for "low voltage" given in IEC 60050-601:1985, 601-01-26.

- operating pressure: maximum allowable working pressure of less than 0,1 MPa (gauge) for the fuel and oxidant passages;
- fuel: gaseous fuel (natural gas, liquefied petroleum gas, propane, butane, hydrogen, etc.) or liquid fuel (kerosene, methanol, etc.);
- oxidant: air.

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

This document covers fuel cell power systems whose primary purpose is the production of electric power and whose secondary purpose may be the utilization of heat. Accordingly, fuel cell power systems for which the use of heat is primary and the use of electric power is secondary are outside the scope of this document.

All systems with integrated batteries are covered by this document. This includes systems where batteries are recharged internally or recharged from an external source.

This document does not cover additional auxiliary heat generators that produce thermal energy.

#### 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.

CISPR 11, *Industrial, scientific and medical equipment – Radio-frequency disturbance characteristics – Limits and methods of measurement*

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

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-8, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test*

IEC 61000-4-11, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests*

IEC 61000-6-1:2005, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments*

IEC 62282-3-200:2015, *Fuel cell technologies – Part 3-200: Stationary fuel cell power systems – Performance test methods*

### 3 Terms and definitions

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

##### **noise level**

sound pressure level produced by the fuel cell power system

Note 1 to entry: Expressed as decibels (dB) and measured as described in 15.2.

#### 3.2

##### **background noise level**

sound pressure level of ambient noise at the measurement point

Note 1 to entry: This measurement is taken as described in 15.2 with the fuel cell power system in the cold state.

#### 3.3

##### **battery**

electrochemical energy storage device that provides energy input to auxiliary machines and equipment necessary to operate the fuel cell power system and/or provides electric energy output

Note 1 to entry: Back-up batteries for control software memory and similar applications are not included.

#### 3.4

##### **cold state**

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

[SOURCE: IEC TS 62282-1:2013, 3.110.1, modified — "ready for start-up" added.]

### 3.5

#### **mass discharge rate**

mass of discharged exhaust gas component per unit of time

### 3.6

#### **discharge water**

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

Note 1 to entry: Discharge water does not constitute part of a thermal recovery system.

[SOURCE: IEC TS 62282-1:2013, 2.2, modified — Note 1 to entry added.]

### 3.7

#### **electrical efficiency**

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

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

[SOURCE: IEC TS 62282-1:2013, 3.30.1, modified — "average" added to "net electric power output"; "average fuel power input" instead of "total enthalpy flow".]

### 3.8

#### **electric energy input**

integrated value of electric power input at the electric input terminal

### 3.9

#### **electric energy output**

integrated value of electric power output at the electric output terminal

### 3.10

#### **electric power input**

electric power input at the electric input terminal of the fuel cell power system

### 3.11

#### **electric power output**

electric power output at the electric output terminal of the fuel cell power system

### 3.12

#### **fuel cell power system**

generator system that uses one or more fuel cell module(s) to generate electric power and heat

[SOURCE: IEC TS 62282-1:2013, 3.49, modified — Note 1 to entry deleted.]

### 3.13

#### **fuel input**

amount of natural gas, hydrogen, methanol, liquid petroleum gas, propane, butane, or other material containing chemical energy entering the fuel cell power system while it is working at the specified operating conditions

### 3.14

#### **fuel power input**

fuel energy input per unit of time

**3.15****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 TS 62282-1:2013, 3.30.3, 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.]

**3.16****heat recovery fluid**

fluid circulating between the fuel cell power system and a heat sink for recovering the thermal energy output

**3.17****inert purge gas**

inert gas or dilution gas, not containing chemical energy, supplied to the fuel cell power system during specific conditions to make it ready for operation or shutdown

Note 1 to entry: Dilution gas containing chemical energy shall be considered as fuel.

**3.18****integrated fuel input**

volume or mass of fuel consumed by the fuel cell power system under specified operating conditions

**3.19****interface point**

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

Note 1 to entry: This boundary is intentionally selected to accurately measure the performance of the system. If necessary, the boundary or the interface points of the fuel cell power system (Figure 2) to be assessed should be determined by agreement of the parties.

[SOURCE: IEC TS 62282-1:2013, 3.65]

**3.20****mass concentration**

concentration of mass of exhaust gas component per unit of volume

**3.21****minimum electric power output**

minimum net power output, at which a fuel cell power system is able to operate continuously at a steady state

**3.22****net electric power output**

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

[SOURCE: IEC TS 62282-1:2013, 3.85.3, modified — “output” added to the term, Notes 1 and 2 to entry deleted.]

**3.23****rated electric power output**

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 TS 62282-1:2013, 3.85.4, modified — “electric” and “output” added to the term, Note 1 to entry deleted.]

**3.24**  
**operation cycle**

complete sequence of successive operation phases of a fuel cell power system comprising start-up, ramp-up, rated operation and shutdown

**3.25**  
**operation cycle electrical efficiency**

ratio of the net electric energy output of a fuel cell power system to the fuel energy fed to the same fuel cell power system during a complete operation cycle comprising start-up, ramp-up, rated operation and shutdown

**3.26**  
**overall energy efficiency**

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

[SOURCE: IEC TS 62282-1:2013, 3.30.4 modified — alternative expression “or total thermal efficiency” deleted; “power output” instead of “energy flow”; “average total power input” instead of “total enthalpy flow”; Note 1 to entry deleted.]

**3.27**  
**pre-generation state**

state of a fuel cell power system being 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 substantial electric active power output

[SOURCE: IEC TS 62282-1:2013, 3.110.4]

**3.28**  
**ramp-up energy**

electric and/or chemical (fuel) energy required for transitioning from positive net electric power output after start-up to rated net electric power output

**3.29**  
**ramp-up time**

duration required for transitioning from positive net electric power output after start-up to rated net electric power output

**3.30**  
**recovered heat**

thermal energy that has been recovered for useful purpose

Note 1 to entry: The recovered heat is measured by determining the temperatures and flow rates of the 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.

[SOURCE: IEC TS 62282-1:2013, 2.2, modified — Note 1 to entry added.]

**3.31**  
**recovered thermal power**

recovered heat per unit of time

**3.32**  
**shutdown energy**

sum of electric and/or chemical (fuel) energy required during the shutdown time

**3.33****shutdown time**

duration between the instant when a shutdown action is initiated at rated electric power output and the instant when the cold state or storage state, as specified by the manufacturer, is attained

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

[SOURCE: IEC TS 62282-1:2013, 3.115.4, modified — “a shutdown action is initiated at rated electric power output” instead of “the load is removed”; “the cold state or storage state is attained” instead of “the shutdown is completed”.]

**3.34****start-up energy**

- a) <fuel cell power systems without battery> sum of electric, thermal and/or chemical (fuel) energy required for transitioning from cold state or storage state to positive net electric power output; and
- b) <fuel cell power systems with battery> sum of electric, thermal and/or chemical (fuel) energy required for recharging the battery, which is discharged to supply rated electric power output during start-up time, to a known nominal state of charge

[SOURCE: IEC TS 62282-1:2013, 3.109, modified with addition of domain — case b) added, “for transitioning from cold state or storage state to positive net electric power output” instead of “during the start -up time”.]

**3.35****start-up time**

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

[SOURCE: IEC TS 62282-1:2013, 3.115.5, modified — “positive” added]

**3.36****stationary fuel cell power system**

fuel cell power system that is connected and fixed in place

[SOURCE: IEC TS 62282-1:2013, 3.49.3]

**3.37****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 and/or electric energy and/or an inert atmosphere in order to prevent deterioration of the components and/or energize the control systems and other components, and is ready for start-up

[SOURCE: IEC TS 62282-1:2013, 3.110.6, modified — “and/or energize the control systems and other components, and is ready for start-up” added.]

**3.38****test run**

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

**3.39****thermal storage unit**

unit that stores heat recovered from the fuel cell power system in the thermal storage medium and supplies the heat with heat carrier externally as needed

Note 1 to entry: It is composed of a thermal storage tank, a heat exchanger and a heat carrier supply system.

Note 2 to entry: A typical thermal storage medium is water.

**3.40****waste heat**

thermal energy released and not recovered

[SOURCE: IEC TS 62282-1:2013, 2.2]

**A1 3.41****test duration**

duration of the complete test for the estimation of the electric and heat recovery efficiency up to ten years of operation, comprising a specific number of test runs

**3.42****degradation rate**

reduction of the electric efficiency of a stationary fuel cell power system per time of operation

Note 1 to entry: The degradation rate is expressed in efficiency per cent points per time (%/h). 

**4 Symbols**

The symbols and their meanings used in this part of IEC 62282 are given in Table 1 for electrical/thermal performance and Table 2 for environmental performance, with the appropriate units.

**Table 1 – Symbols and their meanings  
for electric and thermal performance**

| Symbol                    | Definition                                                                                                    | Unit              |
|---------------------------|---------------------------------------------------------------------------------------------------------------|-------------------|
| <b><math>c</math></b>     | <b>Specific heat</b>                                                                                          |                   |
| $c_{HR}$                  | Specific heat capacity of heat recovery fluid                                                                 | kJ/(kg·K)         |
| <b><math>E</math></b>     | <b>Energy</b>                                                                                                 |                   |
| $E_{mf}$                  | Energy input of gaseous fuel per unit mass                                                                    | kJ/kg             |
| $E_{vf}$                  | Energy input of the fuel per unit volume                                                                      | kJ/m <sup>3</sup> |
| $E_{fin}$                 | Fuel energy input                                                                                             | kJ                |
| $E_{finstbat}$            | Fuel energy input required during start-up time for system with battery                                       | kJ                |
| $E_{finst}$               | Fuel energy input required during start-up time                                                               | kJ                |
| $E_{finramp}$             | Fuel energy input required during ramp-up time                                                                | kJ                |
| $E_{finshut}$             | Fuel energy input required during shutdown time                                                               | kJ                |
| $E_{fincyc}$              | Fuel energy input required for an operating cycle from start-up, over ramp-up and rated operation to shutdown | kJ                |
| <b><math>H</math></b>     | <b>Heating value</b>                                                                                          |                   |
| $H_{f0}$                  | Heating value of fuel on a molar basis 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                                                                                  | kJ/kg             |
| <b><math>M</math></b>     | <b>Molar mass</b>                                                                                             |                   |
| $M_f$                     | Molar mass of fuel                                                                                            | kg/mol            |
| <b><math>m</math></b>     | <b>Mass</b>                                                                                                   |                   |
| $m_f$                     | Fuel mass measured over the test duration                                                                     | kg                |
| $m_{HR}$                  | Heat recovery fluid mass                                                                                      | kg                |
| <b><math>P, dP</math></b> | <b>Power, power change rate</b>                                                                               |                   |
| $P_n$                     | Average net electric power output                                                                             | kW                |
| $P_{rated}$               | Rated electric power output                                                                                   | kW                |
| $P_{min}$                 | Minimum electric power output                                                                                 | kW                |
| $P_d$                     | Electric power output change range between $P_{rated}$ and $P_{min}$                                          | kW                |

| Symbol                      | Definition                                                                                                                       | Unit                                   |
|-----------------------------|----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|
| $P_{\text{instore}}$        | Average electric power input in storage state                                                                                    | kW                                     |
| $P_{\text{HR}}$             | Average recovered thermal power                                                                                                  | kJ/s                                   |
| $P_{\text{fin}}$            | Average fuel power input                                                                                                         | kJ/s                                   |
| $dP_{\text{down}}$          | Decrease rate of electric power output                                                                                           | kW/s                                   |
| $dP_{\text{up}}$            | Increase rate of electric power output                                                                                           | kW/s                                   |
| $p$                         | <b>Pressure</b>                                                                                                                  |                                        |
| $p_0$                       | Reference pressure (101,325 kPa(abs))                                                                                            | kPa(abs)                               |
| $p_f$                       | Average fuel pressure                                                                                                            | kPa(abs)                               |
| $q_m$                       | <b>Mass flow rate</b>                                                                                                            |                                        |
| $q_{mf}$                    | Average mass flow rate of fuel                                                                                                   | kg/s                                   |
| $q_{mHR}$                   | Average mass flow rate of heat recovery fluid                                                                                    | kg/s                                   |
| $q_v$                       | <b>Volumetric flow rate</b>                                                                                                      |                                        |
| $q_{vf}$                    | Average volumetric flow rate of fuel under the test conditions                                                                   | m <sup>3</sup> /s                      |
| $q_{vf0}$                   | Average volumetric flow rate of fuel under reference conditions                                                                  | m <sup>3</sup> /s                      |
| $q_{vHR}$                   | Average volumetric flow rate of heat recovery fluid                                                                              | m <sup>3</sup> /s                      |
| $T$                         | <b>Temperature</b>                                                                                                               |                                        |
| $T_0$                       | Reference temperature (288,15 K)                                                                                                 | K                                      |
| $T_f$                       | Average fuel temperature                                                                                                         | K                                      |
| $T_{HR1}$                   | Average temperature of heat recovery fluid output                                                                                | K                                      |
| $T_{HR2}$                   | Average temperature of heat recovery fluid input                                                                                 | K                                      |
| $T_s$                       | Standard temperature (273,15 K)                                                                                                  | K                                      |
| $\Delta T$                  | Temperature difference between heat recovery fluid output and input                                                              | K                                      |
| $t$                         | <b>Time</b>                                                                                                                      |                                        |
| $\Delta t$                  | Test duration                                                                                                                    | $\overline{A_1}$ s, h $\overline{A_1}$ |
| $\overline{A_1} \Delta t_a$ | Number of hours between point s and point a                                                                                      | h $\overline{A_1}$                     |
| $\Delta t_{\text{st}}$      | Start-up time                                                                                                                    | s                                      |
| $\Delta t_{\text{stbat}}$   | Duration from the start-up initiation to battery recharge completion                                                             | s                                      |
| $t_{\text{st1}}$            | Start-up initiation time                                                                                                         |                                        |
| $t_{\text{st2}}$            | Start-up completion time                                                                                                         |                                        |
| $t_{\text{st3bat}}$         | Battery recharge completion time                                                                                                 |                                        |
| $\Delta t_{\text{shut}}$    | Shutdown time                                                                                                                    | s                                      |
| $t_{\text{shut1}}$          | Shutdown initiation time                                                                                                         |                                        |
| $t_{\text{shut2}}$          | Shutdown completion time                                                                                                         |                                        |
| $\Delta t_{\text{lcdown}}$  | Duration of the decrease in electric power output from $t_{\text{lc1}}$ to $t_{\text{lc2}}$                                      | s                                      |
| $\Delta t_{\text{lcup}}$    | Duration of the increase in electric power output from $t_{\text{lc3}}$ to $t_{\text{lc4}}$                                      | s                                      |
| $t_{\text{lc1}}$            | Start time of electric power output decreasing action                                                                            |                                        |
| $t_{\text{lc2}}$            | Time when the electric power output reaches the minimum electric power output within $\pm 2$ % of rated electric power output    |                                        |
| $t_{\text{lc3}}$            | Start time of electric power output increasing action                                                                            |                                        |
| $t_{\text{lc4}}$            | Time when the electric power output reaches the rated electric power output within $\pm 2$ % of rated electric power output      |                                        |
| $t_{\text{rated}}$          | Duration of the rated power output phase of an operation cycle from start-up, over ramp-up and rated power operation to shutdown | s                                      |
| $\Delta t_{\text{ramp}}$    | Ramp-up time                                                                                                                     | s                                      |
| $t_{\text{ramp1}}$          | Ramp-up start time                                                                                                               |                                        |
| $t_{\text{ramp2}}$          | Ramp-up completion time                                                                                                          |                                        |

| Symbol                        | Definition                                                                                                                                                                                                                                                               | Unit                     |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|
| $V$                           | <b>Volume</b>                                                                                                                                                                                                                                                            |                          |
| $V_f$                         | Fuel volume measured over the test duration                                                                                                                                                                                                                              | m <sup>3</sup>           |
| $V_{HR}$                      | Heat recovery fluid volume                                                                                                                                                                                                                                               | m <sup>3</sup>           |
| $V_m$                         | <b>Molar volume</b>                                                                                                                                                                                                                                                      |                          |
| $V_m$                         | Reference molar volume of ideal gas ( $2,364\ 5 \times 10^{-2}$ m <sup>3</sup> /mol at reference temperature $T_0 = 288,15$ K or $2,241\ 4 \times 10^{-2}$ m <sup>3</sup> /mol at standard temperature $T_s = 273,15$ K, both at reference pressure $p_0 = 101,325$ kPa) | m <sup>3</sup> /mol      |
| $W$                           | <b>Electric energy</b>                                                                                                                                                                                                                                                   |                          |
| $W_{out}$                     | Electric energy output                                                                                                                                                                                                                                                   | kW·h                     |
| $W_{outbat}$                  | Electric energy output over the duration from the start-up initiation time, $t_{st1}$ to the battery recharge completion time, $t_{st3bat}$                                                                                                                              | kW·h                     |
| $W_{in}$                      | Electric energy input                                                                                                                                                                                                                                                    | kW·h                     |
| $W_{inbat}$                   | Electric energy input over the duration from the start-up initiation time, $t_{st1}$ to the battery recharge completion time, $t_{st3bat}$                                                                                                                               | kW·h                     |
| $W_{inst}$                    | Electric energy input during start-up time                                                                                                                                                                                                                               | kW·h                     |
| $W_{instbat}$                 | Electric energy required over the duration from the start-up initiation time, $t_{st1}$ to the battery recharge completion time, $t_{st3bat}$                                                                                                                            | kW·h                     |
| $W_{inshut}$                  | Electric energy input during shutdown time                                                                                                                                                                                                                               | kW·h                     |
| $W_{instore}$                 | Electric energy input at storage state                                                                                                                                                                                                                                   | kW·h                     |
| $W_{outramp}$                 | Electric energy output during ramp-up time                                                                                                                                                                                                                               | kW·h                     |
| $W_{outcyc}$                  | Net electric energy output during an operating cycle from start-up, over ramp-up and rated operation to shutdown                                                                                                                                                         | kW·h                     |
| $x$                           | <b>Molar ratio</b>                                                                                                                                                                                                                                                       |                          |
| $x_j$                         | Molar ratio of component $j$                                                                                                                                                                                                                                             |                          |
| $\eta$                        | <b>Efficiency</b>                                                                                                                                                                                                                                                        |                          |
| $\eta_{el}$                   | Electrical efficiency                                                                                                                                                                                                                                                    | %                        |
| $\eta_{th}$                   | Heat recovery efficiency                                                                                                                                                                                                                                                 | %                        |
| $\eta_{total}$                | Overall energy efficiency                                                                                                                                                                                                                                                | %                        |
| $\eta_{cyc}$                  | Operation cycle electrical efficiency                                                                                                                                                                                                                                    | %                        |
| $\overline{\eta}_{el,est,av}$ | Estimated average electric efficiency during one year of operation                                                                                                                                                                                                       | %                        |
| $\eta_{el,est}(k)$            | Estimated electric efficiency at the end of year $k$                                                                                                                                                                                                                     | %                        |
| $\eta_{el,init}$              | Calculated value of the linear regression of the electric efficiency at the time of point a                                                                                                                                                                              | %                        |
| $\Delta\eta_{el}$             | Approximated degradation rate of the electric efficiency                                                                                                                                                                                                                 | %/h                      |
| $\eta_{th,est}(k)$            | Estimated heat recovery efficiency at the end of year $k$                                                                                                                                                                                                                | % $\overline{\eta}_{th}$ |
| $\rho$                        | <b>Density</b>                                                                                                                                                                                                                                                           |                          |
| $\rho_{HR}$                   | Density of heat recovery fluid at $T_{HR1}$                                                                                                                                                                                                                              | kg/m <sup>3</sup>        |

NOTE The main symbols in the fuel cell power system are found in Figure 1.

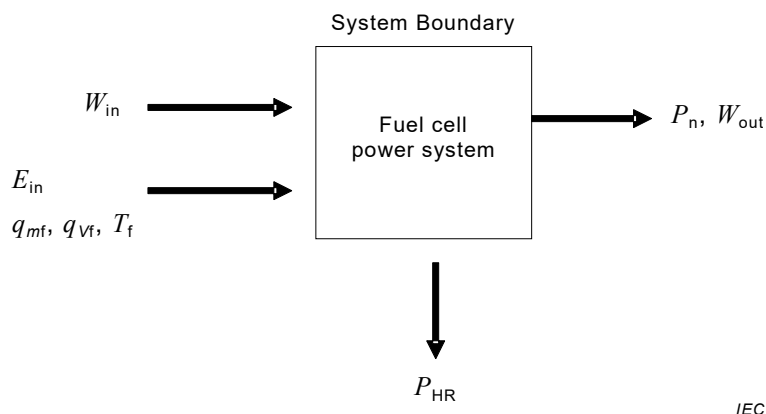


Figure 1 – Symbol diagram

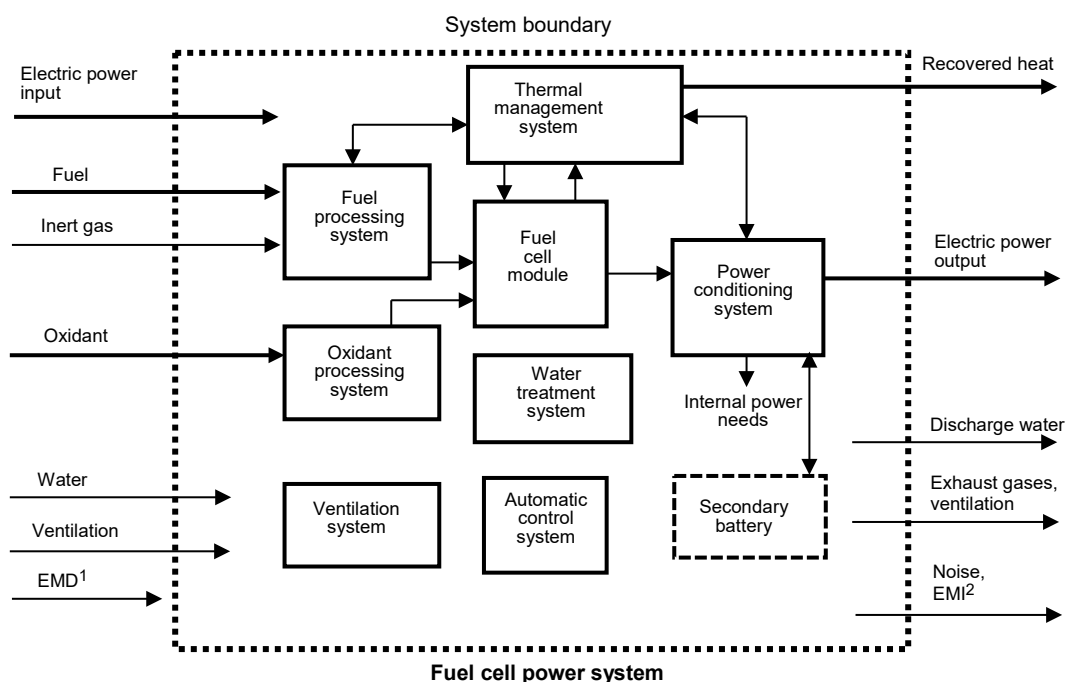
Table 2 – Additional symbols and their meanings  
for environmental performance

| Symbol                         | Definition                                                                                                                                           | Unit                    |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| $M_r$                          | <b>Relative molecular mass</b>                                                                                                                       |                         |
| $M_{r,f}$                      | Compositional relative molecular mass of the fuel                                                                                                    |                         |
| $M_r(\text{CO}_2)$             | Relative molecular mass of $\text{CO}_2$ ( $M_r(\text{CO}_2) \approx 44,01$ )                                                                        |                         |
| $M_r(\text{CO})$               | Relative molecular mass of $\text{CO}$ ( $M_r(\text{CO}) \approx 28,01$ )                                                                            |                         |
| $M_r(\text{THC})$              | Compositional relative molecular mass of THC                                                                                                         |                         |
| $M_r(\text{NO}_x)$             | Relative molecular mass of $\text{NO}_x$ when the entire amount of $\text{NO}_x$ is assumed to be $\text{NO}_2$ ( $M_r(\text{NO}_x) \approx 46,01$ ) |                         |
| $M_r(\text{SO}_2)$             | Relative molecular mass of $\text{SO}_2$ ( $M_r(\text{SO}_2) \approx 64,06$ )                                                                        |                         |
| $q_m$                          | <b>Mass discharge rate</b>                                                                                                                           |                         |
| $q_{m,\text{ex}}(\text{CO}_2)$ | $\text{CO}_2$ mass discharge rate by the exhaust                                                                                                     | g/h                     |
| $q_{m,\text{ex}}(\text{CO})$   | $\text{CO}$ mass discharge rate by the exhaust                                                                                                       | g/h                     |
| $q_{m,\text{ex}}(\text{THC})$  | THC mass discharge rate by the exhaust                                                                                                               | g/h                     |
| $q_{m,\text{ex}}(\text{NO}_x)$ | $\text{NO}_x$ mass discharge rate by the exhaust                                                                                                     | g/h                     |
| $q_{m,\text{ex}}(\text{SO}_2)$ | $\text{SO}_2$ mass discharge rate by the exhaust                                                                                                     | g/h                     |
| $V$                            | <b>Volume ratio</b>                                                                                                                                  |                         |
| $V_{\text{ex,th,dr},V}$        | Theoretical ratio of dry exhaust gas volume per volume of gaseous input fuel                                                                         | $\text{m}^3/\text{m}^3$ |
| $V_{\text{ex,th,dr},m}$        | Theoretical ratio of dry exhaust gas volume per mass of liquid input fuel                                                                            | $\text{m}^3/\text{kg}$  |
| $V_f(\text{H}_2)$              | Volume ratio of $\text{H}_2$ in unit volume per volume of input fuel                                                                                 | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{CO})$               | Volume ratio of $\text{CO}$ in unit volume per volume of input fuel                                                                                  | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{CO}_2)$             | Volume ratio of $\text{CO}_2$ in unit volume per volume of input fuel                                                                                | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{N}_2)$              | Volume ratio of $\text{N}_2$ in unit volume per volume of input fuel                                                                                 | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{CH}_4)$             | Volume ratio of $\text{CH}_4$ in unit volume per volume of input fuel                                                                                | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{C}_2\text{H}_6)$    | Volume ratio of $\text{C}_2\text{H}_6$ in unit volume per volume of input fuel                                                                       | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{C}_3\text{H}_8)$    | Volume ratio of $\text{C}_3\text{H}_8$ in unit volume per volume of input fuel                                                                       | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{C}_4\text{H}_{10})$ | Volume ratio of $\text{C}_4\text{H}_{10}$ in unit volume per volume of input fuel                                                                    | $\text{m}^3/\text{m}^3$ |
| $V_f(\text{C}_5\text{H}_{12})$ | Volume ratio of $\text{C}_5\text{H}_{12}$ in unit volume per volume of input fuel                                                                    | $\text{m}^3/\text{m}^3$ |

| Symbol                          | Definition                                                                                                                                         | Unit                         |
|---------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
| <b>w</b>                        | <b>Mass fraction</b>                                                                                                                               |                              |
| $w(C)$                          | Mass fraction of the element C in unit mass of input fuel                                                                                          | kg/kg                        |
| $w(H)$                          | Mass fraction of the element H in unit mass of input fuel                                                                                          | kg/kg                        |
| $w(S)$                          | Mass fraction of the element S in unit mass of input fuel                                                                                          | kg/kg                        |
| $w(N)$                          | Mass fraction of the element N in unit mass of input fuel                                                                                          | kg/kg                        |
| $w(O)$                          | Mass fraction of the element O in unit mass of input fuel                                                                                          | kg/kg                        |
| <b><math>\alpha</math></b>      | <b>Hydrogen to carbon atom ratio</b>                                                                                                               |                              |
| $\alpha_f$                      | Hydrogen to carbon atom ratio of fuel                                                                                                              |                              |
| $\alpha(THC)$                   | Hydrogen to carbon atom ratio of THC in exhaust gas                                                                                                |                              |
| <b><math>\gamma</math></b>      | <b>Mass concentration</b>                                                                                                                          |                              |
| $\gamma_{ex}(CO)$               | CO mass concentration in dry exhaust gas                                                                                                           | mg/m <sup>3</sup>            |
| $\gamma_{ex}(THC)$              | THC mass concentration in dry exhaust gas                                                                                                          | mg/m <sup>3</sup>            |
| $\gamma_{ex}(NO_x)$             | NO <sub>x</sub> mass concentration in dry exhaust gas                                                                                              | mg/m <sup>3</sup>            |
| $\gamma_{ex}(SO_2)$             | SO <sub>2</sub> mass concentration in dry exhaust gas                                                                                              | mg/m <sup>3</sup>            |
| <b><math>\varepsilon</math></b> | <b>Emission</b>                                                                                                                                    |                              |
| $\varepsilon(CO)$               | Mass of CO emission per unit energy of fuel input                                                                                                  | mg/kW·h                      |
| $\varepsilon(THC)$              | Mass of THC emission per unit energy of fuel input                                                                                                 | mg/kW·h                      |
| $\varepsilon(NO_x)$             | Mass of NO <sub>x</sub> emission per unit energy of fuel input                                                                                     | mg/kW·h                      |
| $\varepsilon(SO_2)$             | Mass of SO <sub>2</sub> emission per unit energy of fuel input                                                                                     | mg/kW·h                      |
| <b><math>\rho</math></b>        | <b>Density</b>                                                                                                                                     |                              |
| $\rho(CO)$                      | CO density                                                                                                                                         | kg/m <sup>3</sup>            |
| $\rho(NO_2)$                    | NO <sub>2</sub> density                                                                                                                            | kg/m <sup>3</sup>            |
| $\rho(SO_2)$                    | SO <sub>2</sub> density                                                                                                                            | kg/m <sup>3</sup>            |
| <b><math>\varphi</math></b>     | <b>Volume fraction</b>                                                                                                                             |                              |
| $\varphi_{B,corr}$              | Corrected volume fraction of the component B                                                                                                       | ml/m <sup>3</sup> ,<br>vol % |
| $\varphi_{B,meas}$              | Measured volume fraction of the component B                                                                                                        | ml/m <sup>3</sup> ,<br>vol % |
| $\varphi_{at}(O_2)$             | Measured value of O <sub>2</sub> volume fraction in atmosphere at air inlet in dry state (in case of fresh air, $\varphi_{at}(O_2) \approx 21\%$ ) | vol %                        |
| $\varphi_{ex}(O_2)$             | Measured O <sub>2</sub> volume fraction in dry exhaust gas                                                                                         | vol %                        |
| $\varphi_{ex,corr}(CO_2)$       | Corrected CO <sub>2</sub> volume fraction in dry exhaust gas                                                                                       | vol %                        |
| $\varphi_{ex,corr}(CO)$         | Corrected CO volume fraction in dry exhaust gas                                                                                                    | ml/m <sup>3</sup>            |
| $\varphi_{ex,corr}(THC)$        | Corrected THC volume fraction in dry exhaust gas (carbon equivalent)                                                                               | ml/m <sup>3</sup>            |
| $\varphi_{ex,corr}(NO_x)$       | Corrected NO <sub>x</sub> volume fraction in dry exhaust gas                                                                                       | ml/m <sup>3</sup>            |
| $\varphi_{ex,corr}(SO_2)$       | Corrected SO <sub>2</sub> volume fraction in dry exhaust gas                                                                                       | ml/m <sup>3</sup>            |

## 5 Configuration of small stationary fuel cell power system

Figure 2 illustrates the general configuration of small stationary fuel cell power systems subject to this document and shows the system boundary and physical quantities entering and leaving the fuel cell power system.



IEC

#### Key

<sup>1</sup> EMD electromagnetic disturbance

<sup>2</sup> EMI electromagnetic interference

**Figure 2 – General configuration of small stationary fuel cell power system**

## 6 Reference conditions

The reference conditions are specified as follows:

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

## 7 Heating value base

The heating value of fuel is based on the lower heating value (LHV) in principle.

In cases where LHV is applied for the calculation of energy efficiency, it is not necessary to add the symbol "LHV", as shown below:

$$\eta_{el}, \eta_{th}, \text{ or } \eta_{total} = XX \%$$

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

$$\eta_{el}, \eta_{th}, \text{ or } \eta_{total} = XX \% \text{ (HHV)}$$

NOTE Heating values of fuels for both LHV and HHV are given in Table A.1.

## 8 Test preparation

### 8.1 General

Clause 8 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 document as their basis. A written test plan shall be prepared.

The following items shall be considered for the test plan:

- a) objective;
- b) test specifications;
- c) test personnel qualifications;
- d) quality assurance standards (e.g. ISO 9000 or other equivalent standards);
- e) target uncertainty;
- f) identification of measurement instruments (refer to Clause 10);
- g) estimated range of test parameters;
- h) data acquisition plan.

### 8.2 Uncertainty analysis

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

- electrical efficiency;
- heat recovery efficiency;
- overall energy efficiency.

NOTE See also Annex A in IEC 62282-3-200:2015.

### 8.3 Data acquisition plan

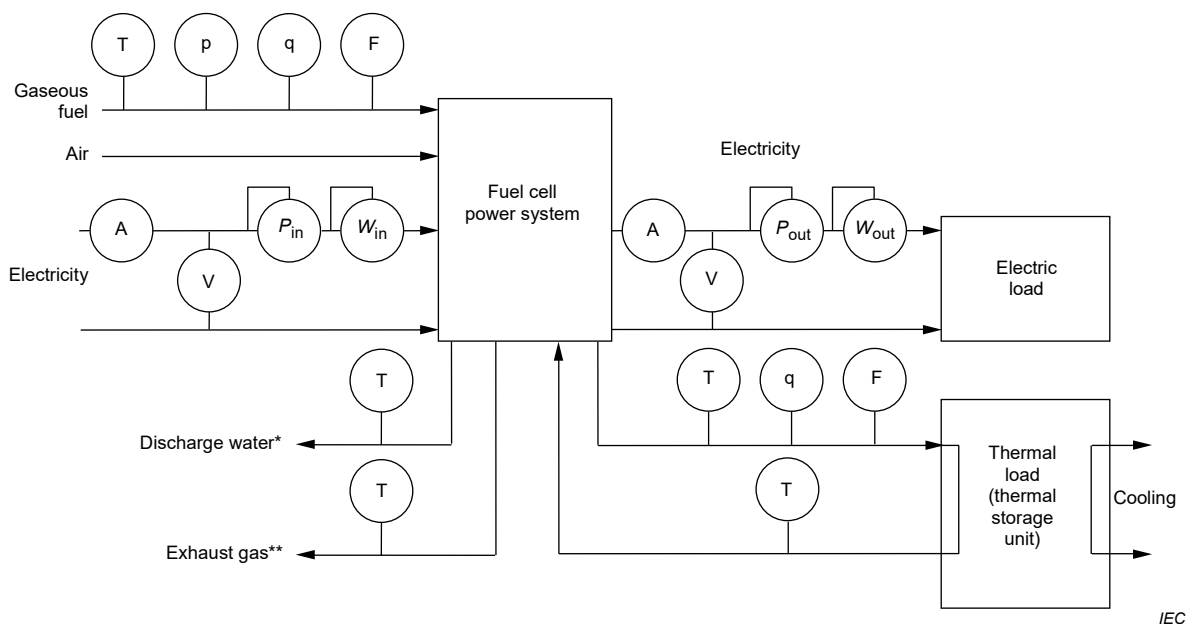
In order to meet the target uncertainty, proper duration and frequency of readings shall be defined and suitable data recording equipment shall be prepared before the performance test.

Automatic data acquisition using a personal computer or similar is preferable.

## 9 Test set-up

Figure 3 and Figure 4 illustrate examples of the test set-up that is required to conduct small stationary fuel cell power system testing with gaseous fuel described in this document. In Figure 3, an electric load and a thermal load are connected to a fuel cell power system. Figure 3 illustrates the measurement of electric characteristics and heat recovery characteristics of the system. A thermal storage unit, which stores heat recovered from the fuel cell power system in the thermal storage medium can be used as the thermal load. In Figure 4, only an electric load is connected to the fuel cell power system. Figure 4 illustrates the measurement of electric characteristics of the system.

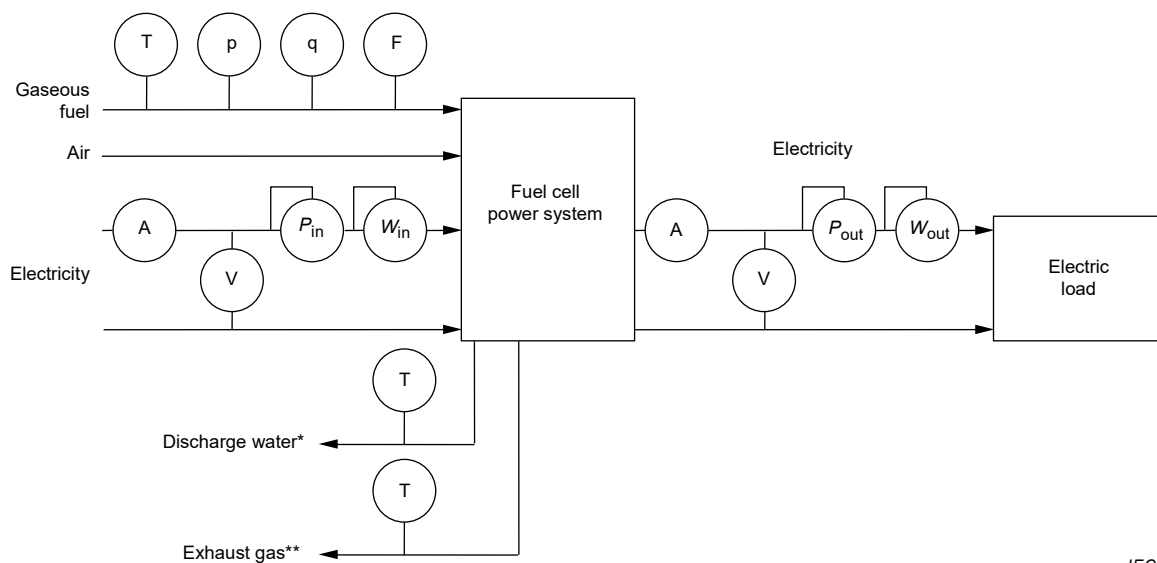
Ⓐ) For the electric demand-following test (14.14), the electric load shall be capable of applying or simulating an electric load profile to the system. It may be replaced or upgraded by a device, which is capable of doing this. Alternatively, the tested small stationary fuel cell power system may be equipped with means for setting and operating a load profile. Ⓐ)



#### Key

See key for Figure 4.

**Figure 3 – Test set-up for small stationary fuel cell power system fed with gaseous fuel which supplies electricity and useful heat**

**Key**

- (A) ammeter
- (V) voltmeter
- (T) thermometer
- (p) pressure gauge
- (q) flowmeter
- (F) integrating flowmeter
- (P) electric power meter
- (W) electric energy meter

\* to collecting device to measure volume (or mass), pH, BOD (biochemical oxygen demand), COD (chemical oxygen demand)

\*\* to collecting device to analyse components

**Figure 4 – Test set-up for small stationary fuel cell power system fed with gaseous fuel which supplies only electricity**

## 10 Instruments and measurement methods

### 10.1 General

Measurement instruments and measurement methods shall conform to the relevant international standards. They shall be selected to meet the measurement range specified by the manufacturer and the required accuracy of measurements.