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Fuel cell technologies –

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

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



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CONTENTS

FOREWORD	6
INTRODUCTION	8
INTRODUCTION to Amendment 1	8
1 Scope	9
2 Normative references	9
3 Terms and definitions	10
4 Symbols	15
5 Configuration of small stationary fuel cell power system	20
6 Reference conditions	20
7 Heating value base	20
8 Test preparation	21
8.1 General	21
8.2 Uncertainty analysis	21
8.3 Data acquisition plan	21
9 Test set-up	21
10 Instruments and measurement methods	23
10.1 General	23
10.2 Measurement instruments	24
10.3 Measurement points	24
10.4 Minimum required measurement systematic uncertainty	26
11 Test conditions	26
11.1 Laboratory conditions	26
11.2 Installation and operating conditions of the system	27
11.3 Power source conditions	27
11.4 Test fuel	27
12 Operating process	27
13 Test plan	29
14 Type tests on electric and thermal performance	30
14.1 General	30
14.2 Fuel consumption test	30
14.2.1 Gaseous fuel consumption test	30
14.2.2 Liquid fuel consumption test	33
14.3 Electric power output test	34
14.3.1 General	34
14.3.2 Test method	34
14.3.3 Calculation of average net electric power output	34
14.4 Heat recovery test	34
14.4.1 General	34
14.4.2 Test method	35
14.4.3 Calculation of average recovered thermal power	35
14.5 Start-up test	36
14.5.1 General	36
14.5.2 Determination of state of charge of the battery	36
14.5.3 Test method	37

14.5.4	Calculation of results	39
14.6	Ramp-up test	40
14.6.1	General	40
14.6.2	Test method	41
14.6.3	Calculation of results	41
14.7	Storage state test	42
14.7.1	General	42
14.7.2	Test method	42
14.7.3	Calculation of average electric power input in storage state	42
14.8	Electric power output change test	42
14.8.1	General	42
14.8.2	Test method	42
14.8.3	Calculation of electric power output change rate	44
14.9	Shutdown test	45
14.9.1	General	45
14.9.2	Test method	45
14.9.3	Calculation of results	46
14.10	Computation of efficiency	47
14.10.1	General	47
14.10.2	Electrical efficiency	47
14.10.3	Heat recovery efficiency	47
14.10.4	Overall energy efficiency	48
14.11	Rated operation cycle efficiency	48
14.11.1	General	48
14.11.2	Calculation of the operation cycle fuel energy input	48
14.11.3	Calculation of the operation cycle net electric energy output	49
14.11.4	Calculation of the operation cycle electrical efficiency	50
14.12	Electromagnetic compatibility (EMC) test	50
14.12.1	General requirement	50
14.12.2	Electrostatic discharge immunity test	51
14.12.3	Radiated, radio-frequency, electromagnetic field immunity test	51
14.12.4	Electrical fast transient/burst immunity test	51
14.12.5	Surge immunity test	51
14.12.6	Immunity test of conducted disturbances induced by radio-frequency fields	51
14.12.7	Power frequency magnetic field immunity test	51
14.12.8	Voltage dips and voltage interruptions	51
14.12.9	Radiated disturbance (emission) measurement test	52
14.12.10	Conducted disturbance (emission) measurement test	52
14.12.11	Power line harmonics emission measurement test	52
14.13	Estimation of electric and heat recovery efficiency up to ten years of operation	52
14.13.1	General	52
14.13.2	Test method	53
14.13.3	Calculation of estimated electric efficiency	54
14.13.4	Calculation of estimated heat recovery efficiency	56
14.14	Electric demand-following test	56
14.14.1	General	56
14.14.2	Electric demand profile	56

14.14.3	Test method	57
14.14.4	Calculation of results	58
14.14.5	Calculation of efficiencies	59
15	Type tests on environmental performance	59
15.1	General.....	59
15.2	Noise test	59
15.2.1	General	59
15.2.2	Test conditions	59
15.2.3	Test method	60
15.2.4	Processing of data.....	61
15.3	Exhaust gas test	61
15.3.1	General	61
15.3.2	Components to be measured	61
15.3.3	Test method	61
15.3.4	Processing of data.....	62
15.4	Discharge water test	71
15.4.1	General	71
15.4.2	Test method	71
16	Test reports	72
16.1	General.....	72
16.2	Title page.....	72
16.3	Table of contents	72
16.4	Summary report	72
Annex A	(normative) Heating values for components of natural gases	74
Annex B	(informative) Examples of composition for natural gases and propane gases	76
Annex C	(informative) Example of a test operation schedule.....	78
Annex D	(informative) Typical exhaust gas components.....	79
Annex E	(informative) Guidelines for the contents of detailed and full reports	80
E.1	General.....	80
E.2	Detailed report	80
E.3	Full report	80
Annex F	(informative) Selected duration of rated power operation	81
Bibliography		82
Figure 1	– Symbol diagram	18
Figure 2	– General configuration of small stationary fuel cell power system	20
Figure 3	– Test set-up for small stationary fuel cell power system fed with gaseous fuel which supplies electricity and useful heat.....	22
Figure 4	– Test set-up for small stationary fuel cell power system fed with gaseous fuel which supplies only electricity	23
Figure 5	– Operating states of stationary fuel cell power system without battery	28
Figure 6	– Operating states of stationary fuel cell power system with battery	29
Figure 7	– Example of electric power chart during start-up time for system without battery	37
Figure 8	– Example of electric power chart during start-up time for system with battery	38
Figure 9	– Example of liquid fuel supply systems	39
Figure 10	– Example of electric power chart during ramp-up for system without battery	41

Figure 11 – Electric power output change pattern for system without battery	43
Figure 12 – Electric power output change pattern for system with battery	44
Figure 13 – Example for electric power change stabilization criteria.....	44
Figure 14 – Electric power chart during shutdown time	46
Figure 16 – Example of electric efficiency during ten years of operation	53
Figure 17 – Example of the electric demand of a residential application.....	57
Figure 15 – Noise measurement points for small stationary fuel cell power systems	60
Table 1 – Symbols and their meanings for electric and thermal performance	15
Table 2 – Additional symbols and their meanings for environmental performance	18
Table 3 – Compensation of readings against the effect of background noise.....	60
Table A.1 – Heating values for components of natural gases at various combustion reference conditions for ideal gas	74
Table B.1 – Example of composition for natural gas (%)	76
Table B.2 – Example of composition for propane gas (%)	77
Table C.1 – Example of a test operation schedule	78
Table D.1 – Typical exhaust gas components to be expected for typical fuels	79
Table F.1 – Selected duration of rated power operation	81

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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This consolidated version of the official IEC Standard and its amendment has been prepared for user convenience.

IEC 62282-3-201 edition 2.1 contains the second edition (2017-08) [documents 105/564/CDV and 105/623/RVC] and its amendment 1 (2022-02) [documents 105/839/CDV and 105/866/RVC].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendment 1. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

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

This second 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).

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 the base publication and its amendment will remain unchanged until the stability date indicated on the IEC web site under webstore.iec.ch in the data related to the specific publication. At this date, the publication will be

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

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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.

INTRODUCTION to Amendment 1

This amendment to IEC 62282-3-201:2017 provides a method of estimating the electric and heat recovery efficiency of small stationary fuel cell power systems for a duration of up to ten years of operation. Furthermore, this amendment to IEC 62282-3-201:2017 provides an evaluation method for electric demand-following small stationary fuel cell power systems, which are operating at changing levels of power output. It has been developed as a reference for the life cycle assessment calculations in IEC TS 62282-9-101.

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 ≤ 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]

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
c	Specific heat	
c_{HR}	Specific heat capacity of heat recovery fluid	$\text{kJ}/(\text{kg} \cdot \text{K})$
E	Energy	
E_{mf}	Energy input of gaseous fuel per unit mass	kJ/kg
E_{Vf}	Energy input of the fuel per unit volume	kJ/m^3
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
H	Heating value	
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
M	Molar mass	
M_f	Molar mass of fuel	kg/mol



Symbol	Definition	Unit
m	Mass	
m_f	Fuel mass measured over the test duration	kg
m_{HR}	Heat recovery fluid mass	kg
P, dP	Power, power change rate	
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
$P_{instore}$	Average electric power input in storage state	kW
P_{HR}	Average recovered thermal power	kJ/s
P_{fin}	Average fuel power input	kJ/s
dP_{down}	Decrease rate of electric power output	kW/s
dP_{up}	Increase rate of electric power output	kW/s
p	Pressure	
p_0	Reference pressure (101,325 kPa(abs))	kPa(abs)
p_f	Average fuel pressure	kPa(abs)
q_m	Mass flow rate	
q_{mf}	Average mass flow rate of fuel	kg/s
q_{mHR}	Average mass flow rate of heat recovery fluid	kg/s
q_v	Volumetric flow rate	
q_{vf}	Average volumetric flow rate of fuel under the test conditions	m ³ /s
q_{vf0}	Average volumetric flow rate of fuel under reference conditions	m ³ /s
q_{VHR}	Average volumetric flow rate of heat recovery fluid	m ³ /s
T	Temperature	
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
ΔT	Temperature difference between heat recovery fluid output and input	K
t	Time	
Δt	Test duration	s, h
Δt_a	Number of hours between point s and point a	h
Δt_{st}	Start-up time	s
Δt_{stbat}	Duration from the start-up initiation to battery recharge completion	s
t_{st1}	Start-up initiation time	
t_{st2}	Start-up completion time	
t_{st3bat}	Battery recharge completion time	
Δt_{shut}	Shutdown time	s
t_{shut1}	Shutdown initiation time	
t_{shut2}	Shutdown completion time	
Δt_{lcdown}	Duration of the decrease in electric power output from t_{lc1} to t_{lc2}	s
Δt_{lcup}	Duration of the increase in electric power output from t_{lc3} to t_{lc4}	s
t_{lc1}	Start time of electric power output decreasing action	

Symbol	Definition	Unit
t_{lc2}	Time when the electric power output reaches the minimum electric power output within ± 2 % of rated electric power output	
t_{lc3}	Start time of electric power output increasing action	
t_{lc4}	Time when the electric power output reaches the rated electric power output within ± 2 % of rated electric power output	
t_{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
Δt_{ramp}	Ramp-up time	s
t_{ramp1}	Ramp-up start time	
t_{ramp2}	Ramp-up completion time	
V	Volume	
V_f	Fuel volume measured over the test duration	m ³
V_{HR}	Heat recovery fluid volume	m ³
V_m	Molar volume	
V_m	Reference molar volume of ideal gas ($2,364\ 5 \times 10^{-2}$ m ³ /mol at reference temperature $T_0 = 288,15$ K or $2,241\ 4 \times 10^{-2}$ m ³ /mol at standard temperature $T_s = 273,15$ K, both at reference pressure $p_0 = 101,325$ kPa)	m ³ /mol
W	Electric energy	
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	Molar ratio	
x_j	Molar ratio of component j	
η	Efficiency	
η_{el}	Electrical efficiency	%
η_{th}	Heat recovery efficiency	%
η_{total}	Overall energy efficiency	%
η_{cyc}	Operation cycle electrical efficiency	%
$\eta_{el,est,av}$	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	%
ρ	Density	
ρ_{HR}	Density of heat recovery fluid at T_{HR1}	kg/m ³

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

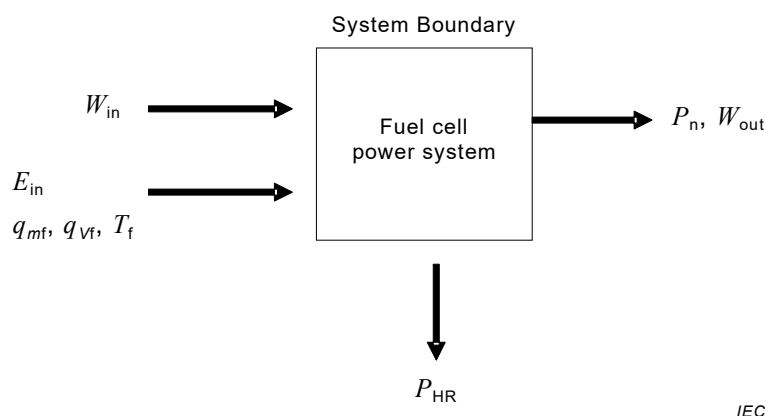


Figure 1 – Symbol diagram

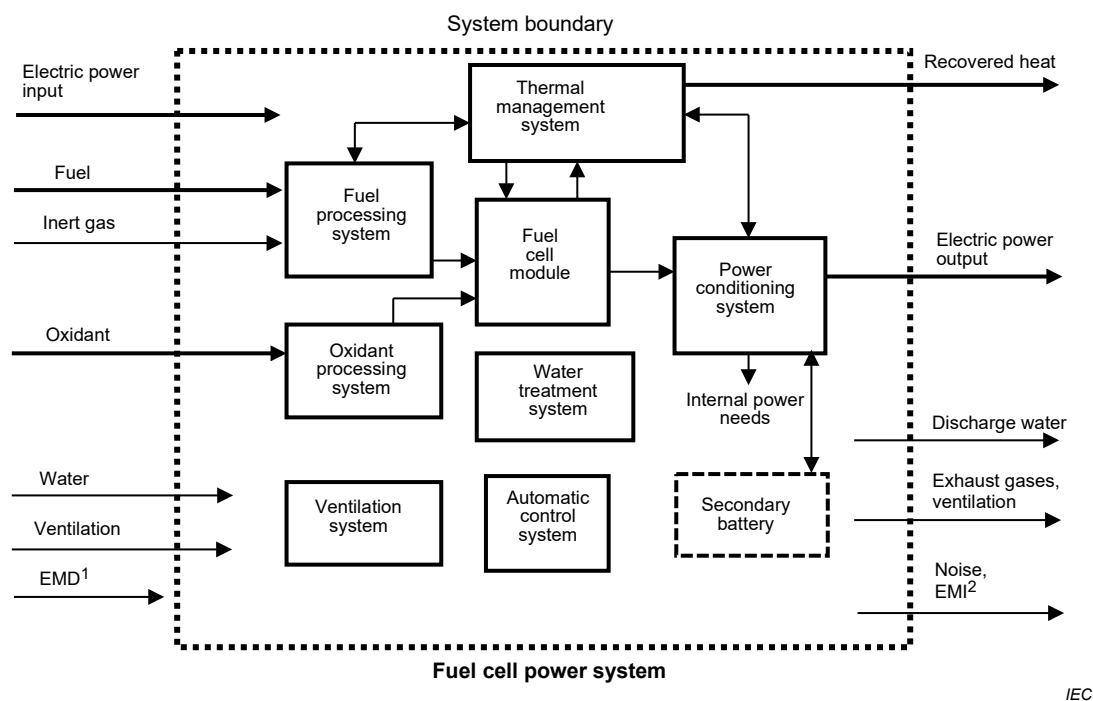
Table 2 – Additional symbols and their meanings
for environmental performance

Symbol	Definition	Unit
M_r	Relative molecular mass	
$M_{r,f}$	Compositional relative molecular mass of the fuel	
$M_r(\text{CO}_2)$	Relative molecular mass of CO_2 ($M_r(\text{CO}_2) \approx 44,01$)	
$M_r(\text{CO})$	Relative molecular mass of 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 NO_x when the entire amount of NO_x is assumed to be NO_2 ($M_r(\text{NO}_x) \approx 46,01$)	
$M_r(\text{SO}_2)$	Relative molecular mass of SO_2 ($M_r(\text{SO}_2) \approx 64,06$)	
q_m	Mass discharge rate	
$q_{m,\text{ex}}(\text{CO}_2)$	CO_2 mass discharge rate by the exhaust	g/h
$q_{m,\text{ex}}(\text{CO})$	CO mass discharge rate by the exhaust	g/h
$q_{m,\text{ex}}(\text{THC})$	THC mass discharge rate by the exhaust	g/h
$q_{m,\text{ex}}(\text{NO}_x)$	NO_x mass discharge rate by the exhaust	g/h
$q_{m,\text{ex}}(\text{SO}_2)$	SO_2 mass discharge rate by the exhaust	g/h
V	Volume ratio	
$V_{\text{ex,th,dr},V}$	Theoretical ratio of dry exhaust gas volume per volume of gaseous input fuel	m^3/m^3
$V_{\text{ex,th,dr},m}$	Theoretical ratio of dry exhaust gas volume per mass of liquid input fuel	m^3/kg
$V_f(\text{H}_2)$	Volume ratio of H_2 in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{CO})$	Volume ratio of CO in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{CO}_2)$	Volume ratio of CO_2 in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{N}_2)$	Volume ratio of N_2 in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{CH}_4)$	Volume ratio of CH_4 in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{C}_2\text{H}_6)$	Volume ratio of C_2H_6 in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{C}_3\text{H}_8)$	Volume ratio of C_3H_8 in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{C}_4\text{H}_{10})$	Volume ratio of C_4H_{10} in unit volume per volume of input fuel	m^3/m^3
$V_f(\text{C}_5\text{H}_{12})$	Volume ratio of C_5H_{12} in unit volume per volume of input fuel	m^3/m^3
w	Mass fraction	
$w(\text{C})$	Mass fraction of the element C in unit mass of input fuel	kg/kg

Symbol	Definition	Unit
$w(H)$	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
α	Hydrogen to carbon atom ratio	
α_f	Hydrogen to carbon atom ratio of fuel	
$\alpha(THC)$	Hydrogen to carbon atom ratio of THC in exhaust gas	
γ	Mass concentration	
$\gamma_{ex}(CO)$	CO mass concentration in dry exhaust gas	mg/m ³
$\gamma_{ex}(THC)$	THC mass concentration in dry exhaust gas	mg/m ³
$\gamma_{ex}(NO_x)$	NO _x mass concentration in dry exhaust gas	mg/m ³
$\gamma_{ex}(SO_2)$	SO ₂ mass concentration in dry exhaust gas	mg/m ³
ε	Emission	
$\varepsilon(CO)$	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 _x emission per unit energy of fuel input	mg/kW·h
$\varepsilon(SO_2)$	Mass of SO ₂ emission per unit energy of fuel input	mg/kW·h
ρ	Density	
$\rho(CO)$	CO density	kg/m ³
$\rho(NO_2)$	NO ₂ density	kg/m ³
$\rho(SO_2)$	SO ₂ density	kg/m ³
φ	Volume fraction	
$\varphi_{B,corr}$	Corrected volume fraction of the component B	ml/m ³ , vol %
$\varphi_{B,meas}$	Measured volume fraction of the component B	ml/m ³ , vol %
$\varphi_{at}(O_2)$	Measured value of O ₂ 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 ₂ volume fraction in dry exhaust gas	vol %
$\varphi_{ex,corr}(CO_2)$	Corrected CO ₂ volume fraction in dry exhaust gas	vol %
$\varphi_{ex,corr}(CO)$	Corrected CO volume fraction in dry exhaust gas	ml/m ³
$\varphi_{ex,corr}(THC)$	Corrected THC volume fraction in dry exhaust gas (carbon equivalent)	ml/m ³
$\varphi_{ex,corr}(NO_x)$	Corrected NO _x volume fraction in dry exhaust gas	ml/m ³
$\varphi_{ex,corr}(SO_2)$	Corrected SO ₂ volume fraction in dry exhaust gas	ml/m ³

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.



Key

- ¹ EMD electromagnetic disturbance
- ² 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: $T_0 = 288,15 \text{ K}$ ($15 \text{ }^\circ\text{C}$);
- 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:

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

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

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

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.

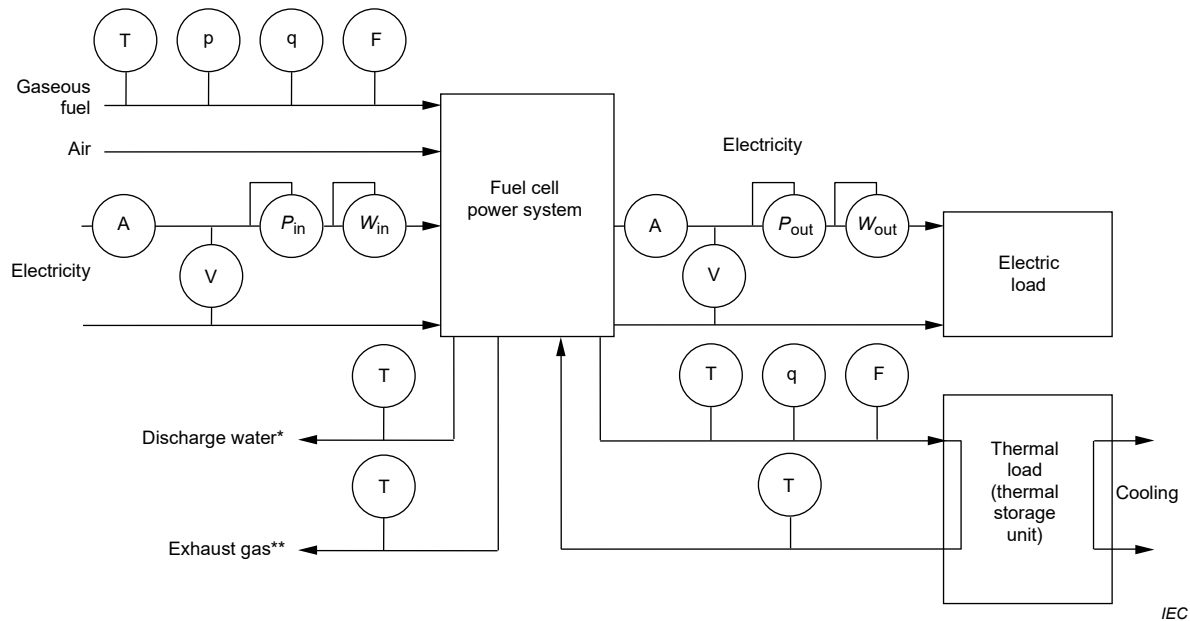
Automatic data acquisition using a personal computer or similar is preferable.

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

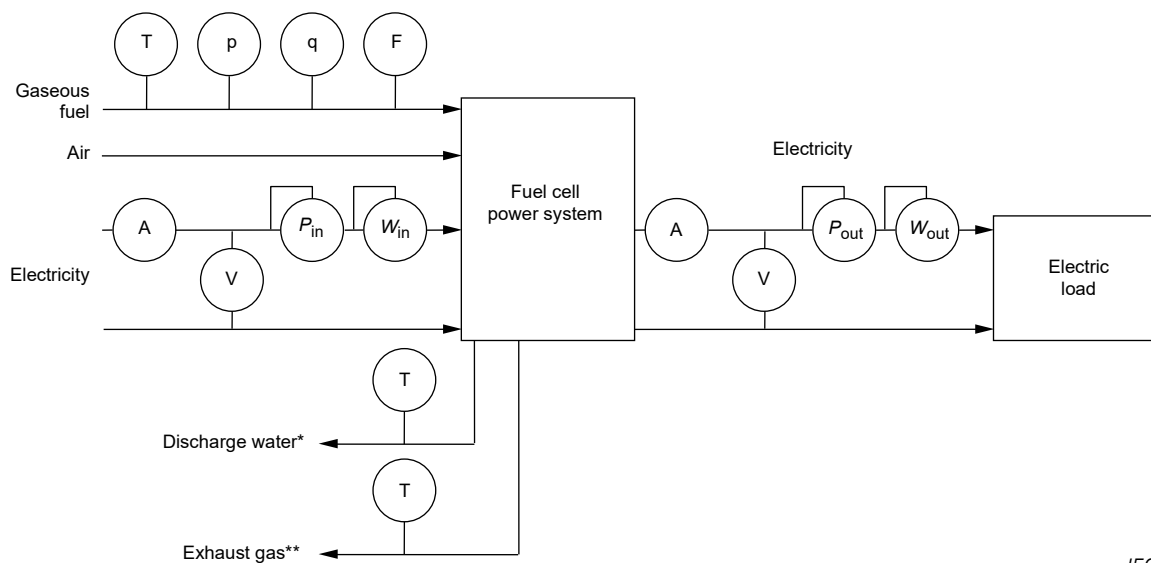
which is capable of doing this. Alternatively, the tested small stationary fuel cell power system may be equipped with means for setting and operating a load profile.



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



IEC

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.

10.2 Measurement instruments

Measurement instruments are listed according to their intended use:

- a) apparatus for measuring the electric power output, electric power input, electric energy input, and electric energy output:
 - electric power meters, electric energy meters, voltmeters, ammeters;
 - for systems that include batteries, a high-speed voltage recorder such as an oscilloscope is required for measuring the increase rate of electric power because the rate is extremely rapid in general (in the order of milliseconds).
- b) apparatus for measuring fuel input:
 - flowmeters, integrating flowmeters, scales, pressure sensors, temperature sensors;
- c) apparatus for measuring fuel composition:
 - gas chromatographs, mass spectrometers, absorption spectrometers;
- d) apparatus for measuring the thermal energy output (only in cases of utilization of the heat):
 - flowmeters, integrating flowmeters, temperature sensors;
- e) apparatus for measuring ambient conditions:
 - barometers, hygrometers, and temperature sensors;
- f) apparatus for measuring the noise level:
 - sound level meters as specified in IEC 61672-1 or other measuring instruments of equivalent or better accuracy;

The settings of the measuring instruments are as follows:

- frequency-weighted characteristic: A;
 - time-weighted characteristic: S;
 - unit: dB (for characteristic A, the display of the frequency-weighted characteristic may be omitted);
- g) apparatus for measuring volume fractions (concentrations) of the exhaust gas components:
 - oxygen analyser (e.g. based on paramagnetic, electrochemical or zirconium oxide sensors);
 - carbon dioxide analyser (e.g. GC-MS or based on infrared absorption sensor);
 - carbon monoxide analyser (e.g. based on nondispersive infrared or electrochemical sensor);
 - nitrogen oxide analyser (e.g. based on nondispersive infrared or electrochemical sensor);
 - sulfur oxide analyser (e.g. FTIR or based on electrochemical sensor);
 - THC analyser (e.g. a flame ionizer detector (FID));
 - h) apparatus for determining the discharge water:
 - graduated cylinder (for volume measurement), temperature sensor, pH meters, BOD probes.

NOTE BOD means biochemical oxygen demand, COD stands for chemical oxygen demand, and THC is total hydrocarbon.

10.3 Measurement points

Measurement points for different parameters are described below.

- a) Gaseous fuel flow rate:
 - place a flowmeter for fuel on the fuel supply line to the fuel cell power system to measure the fuel flow rate.
- b) Gaseous integrated fuel input:

place an integrating flowmeter for fuel on the fuel supply line to the fuel cell power system to measure the fuel input. The integrating flowmeter may combine a flowmeter that measures the fuel flow rate.

- c) Liquid fuel input mass:
place scales under the fuel tank or the entire system, including the fuel tank, to measure the mass of fuel.
- d) Fuel temperature:
connect a thermometer immediately downstream of the fuel flowmeter.
- e) Fuel pressure:
place a pressure meter immediately downstream of the fuel flowmeter to measure the gauge pressure of fuel.
- f) Electric power output:
connect an electric power meter to the electric power output terminal of the fuel cell power system and close to the system boundary.
- g) Electric power input:
connect an electric power meter to the electric power input terminal of the fuel cell power system and close to the system boundary. In case no separate electric power input terminal is existing, this measuring point can be substituted with the electric power output, providing that it is equipped with a bidirectional meter.
- h) Electric energy output:
connect an electric energy meter to the electric power output terminal of the fuel cell power system and close to the system boundary. The electric energy meter may incorporate an electric power meter that indicates electric power output.
- i) Electric energy input:
connect an electric energy meter to the electric power input terminal of the fuel cell power system and close to the system boundary. The electric energy meter may incorporate an electric power meter that indicates electric power input. In case no separate electric energy input terminal is existing, this measuring point can be substituted with the electric energy output, providing that it is equipped with a bidirectional meter.
- j) Fuel composition:
the fuel used during the tests shall be sampled either from the fuel tank or the supply line and analysed on its composition. Fuel sampling and analysis are not required if pre-analysed bottled fuel is used, provided that the uncertainty of the analysed gas is consistent with the uncertainty required by the test.
- k) Heat recovery fluid flow rate (only in utilization of heat):
place a fluid flowmeter on the heat recovery fluid circulation line (outgoing line or returning line) that is plumbed between the fuel cell power system and the thermal load and close to the system boundary. The circulation line shall be insulated to minimize heat loss.
- l) Integrated heat recovery fluid flow (only in utilization of heat):
place an integrating flowmeter on the heat recovery fluid circulation line (outgoing line or returning line) that is plumbed between the fuel cell power system and the thermal load and close to the system boundary. An integrating flowmeter may incorporate a flowmeter that indicates the flow rate of the heat recovery fluid.
- m) Outgoing heat recovery fluid temperature (only in utilization of heat):
place a thermometer on the outgoing heat recovery fluid line and close to the system boundary.
- n) Returning heat recovery fluid temperature (only in utilization of heat):
place a thermometer on the returning heat recovery fluid line and close to the system boundary.
- o) Composition of heat recovery fluid (only in utilization of heat):
sample the heat recovery fluid from the heat recovery system and analyse its components in order to calculate the specific heat. If water is to be used as the heat recovery fluid, the composition analysis may be omitted by using 4,186 kJ/(kg·K) for its specific heat.

- p) Atmospheric pressure:
place an absolute pressure meter adjacent to the fuel cell power system where it will not be affected by ventilation of the fuel cell power system.
- q) Atmospheric temperature:
place a thermometer adjacent to the fuel cell power system where the thermometer will not be affected by air intake or exhaust of the fuel cell power system.
- r) Atmospheric humidity:
place a hygrometer adjacent to the fuel cell power system where the hygrometer will not be affected by air intake or exhaust of the fuel cell power system.
- s) Noise level:
see 15.2.2.2.
- t) Exhaust gas:
place one or more exhaust gas collecting probes combined with a temperature sensor in the exhaust stream at the exhaust gas outlet; see Figure 3.
- u) Discharge water:
place a discharge water reservoir combined with a temperature sensor at the discharge water outlet; see Figure 3.

10.4 Minimum required measurement systematic uncertainty

Test equipment should be chosen in a way that the systematic uncertainty of measurement is below 3 % for overall and thermal efficiencies, and below 2 % for electrical efficiency.

In order to reach the desired efficiency uncertainties, the following systematic measurement uncertainties of the equipment are recommended. They are given in percentage of measured/calculated values or as absolute values:

- electric power: ± 1 %;
- electric energy: ± 1 %;
- fuel gas flow rate: ± 1 %;
- integrated gas flow: ± 1 %;
- liquid flow rate: ± 1 %;
- time: $\pm 0,5$ %;
- mass: ± 1 % of the mass to be determined (not including the tare weight);
- heat recovery fluid temperature: ± 2 % of $\Delta T = T_{HR1} - T_{HR2}$;
Minimum ΔT of 10 K is recommended for precise measurement of ΔT .
- relative humidity: ± 5 %;
- absolute pressure: ± 1 %;
- fuel gas and discharge water temperature: ± 1 K;
- exhaust gas temperature: ± 4 K.

11 Test conditions

11.1 Laboratory conditions

Unless otherwise specified, performance shall be tested in the environment specified below:

- temperature: $20\text{ °C} \pm 15\text{ °C}$;
- humidity: $65\text{ \%} \pm 20\text{ \%}$ relative humidity;
- pressure: between 91 kPa (abs) and 106 kPa (abs).

For each test run, the laboratory conditions shall be measured. As air quality may affect fuel cell power system performance, laboratory air composition (CO₂, CO, SO₂ and so forth) shall be reported with the test result.

11.2 Installation and operating conditions of the system

The installation and operating conditions of the fuel cell power system shall be the conditions specified by the manufacturer (as described in the instruction manual or otherwise) unless otherwise provided.

11.3 Power source conditions

a) Systems without a secondary battery condition

Unless otherwise provided, any systems without batteries that use residential mains shall be tested at the rated voltage and frequency. Any tests that will not be affected by these conditions may deviate from this provision.

b) Systems using secondary battery condition

Systems with batteries may be equipped with a means (for example, a display method or an output signal) to identify that the battery has reached a known nominal state of charge (including full charge state) that is determined by the manufacturer.

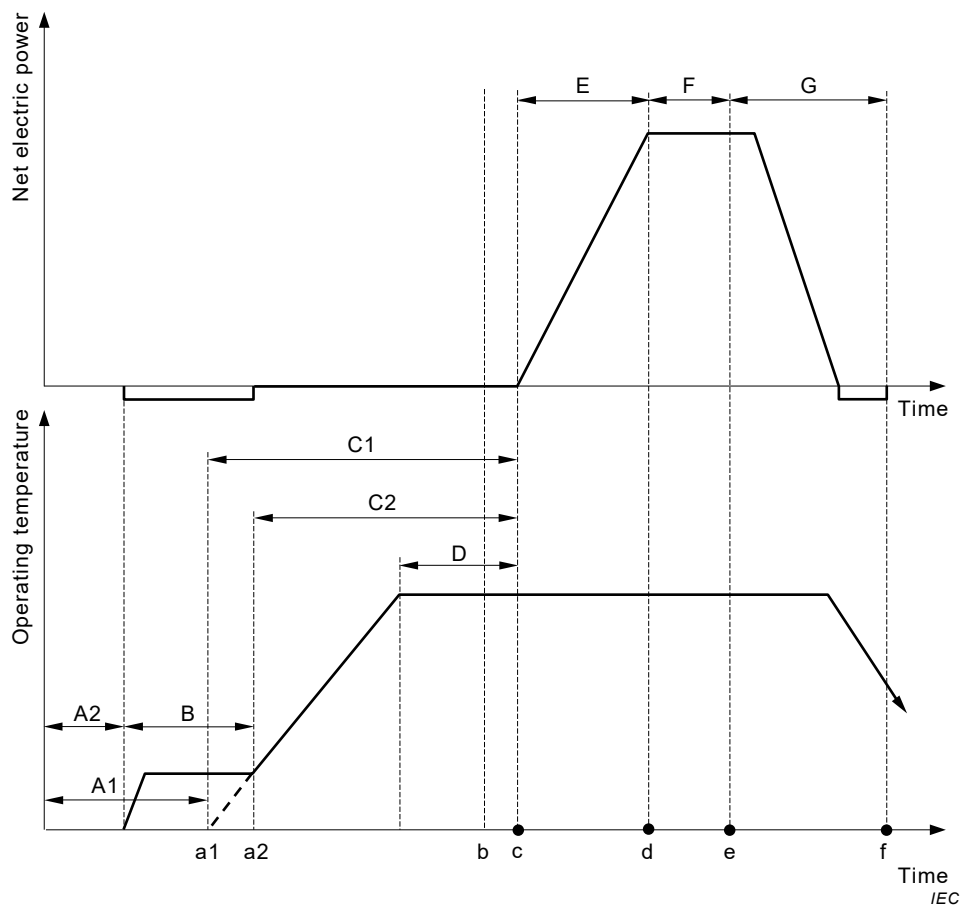
NOTE In the absence of such an indication, the results of energy consumption and efficiency calculations will be less precise. See 14.5.1.

11.4 Test fuel

The test fuel shall be specified by the fuel cell power system manufacturer. Typical examples of natural gas and propane gas compositions are listed in Tables B.1 and B.2, respectively. The composition of the fuel shall be reported.

12 Operating process

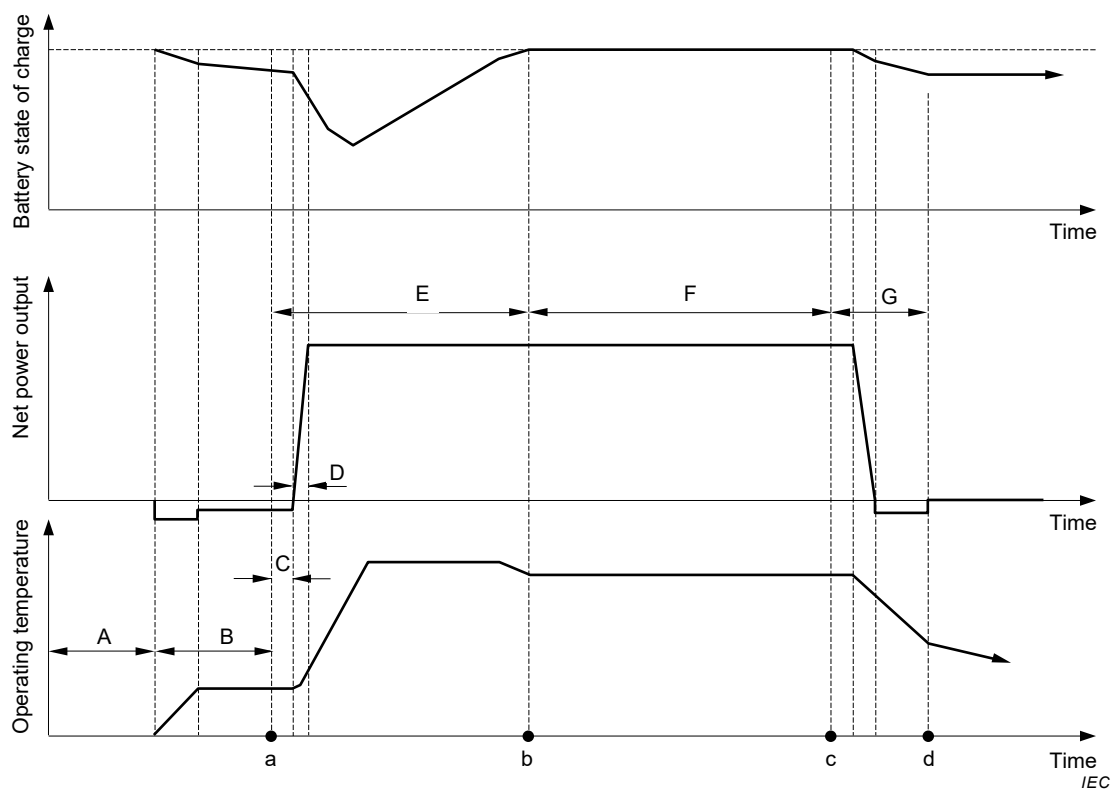
Figure 5 shows the typical operating states of a stationary fuel cell power system without a battery, and Figure 6 shows that of a fuel cell power system with a battery. These figures show a chronological series of changes in the operating state from start-up, to generation, and to shutdown, and provide definitions for the terms corresponding to the different operating states.



Key

A1 or A2	cold state
B	storage state
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	ramp-up time
F	rated power output phase
G	shutdown time
a1 or a2	time when start-up is initiated
b	time when output action is initiated
c	time when start-up action is completed, time when ramp-up starts
d	time when ramp-up is completed
e	time when shutdown action is initiated
f	time when shutdown action is completed (shutdown completion conditions as specified by the manufacturer)
a1 or a2 to f	operation cycle (from the initiation of start-up to the completion of shutdown)

Figure 5 – Operating states of stationary fuel cell power system without battery



Key

- A cold state
- B storage state
- C start-up time
- D ramp-up time
- E time from start-up initiation to battery recharge completion
- F rated power output phase
- G shutdown time
- a time when start-up (output action) is initiated
- b battery recharge completion time
- c time when shutdown action is initiated
- d time when shutdown action is completed (shutdown completion conditions as specified by the manufacturer)
- a to d operation cycle (from the initiation of start-up to the completion of shutdown)

Figure 6 – Operating states of stationary fuel cell power system with battery

13 Test plan

The type tests defined in the following clauses can be partially carried out concurrently. For optimization of the test proceeding and planning of the type tests, an exemplary test operation schedule is presented in Annex C.

14 Type tests on electric and thermal performance

14.1 General

The type tests on electrical/thermal performance include:

- fuel consumption test (14.2);
- electric power output test (14.3);
- heat recovery test (14.4);
- start-up test (14.5);
- ramp-up test (14.6);
- storage state test (14.7);
- electric power output change test (14.8);
- shutdown test (14.9); and
- electromagnetic compatibility (EMC) test (14.12).

The fuel consumption test (14.2), electric power output test (14.3), and heat recovery test (14.4) shall be executed concurrently. The results of these three tests shall be used for the computation of efficiency (14.10), which comprises electrical efficiency (14.10.2), heat recovery efficiency (14.10.3), and overall energy efficiency (14.10.4).

14.2 Fuel consumption test

14.2.1 Gaseous fuel consumption test

14.2.1.1 General

This test is for measuring the gaseous fuel input at rated electric power output. If operation at partial loads 50 %, 75 % and/or minimum power electric output are specified by the manufacturer, these operating points shall be measured as well.

This test shall be carried out concurrently with the electric power output test (14.3) and heat recovery test (14.4).

14.2.1.2 Test method

- a) Operate the system at the rated electric power output for more than 30 min before starting the test.
- b) For systems including batteries, operate the system at rated electric power output for more than 30 min and until a known nominal state of charge of the battery is reached, before starting the test.
- c) Start the test while keeping the system operating at the rated electric power output. If such operation is specified by the manufacturer, repeat the test at partial loads 50 % and 75 % of rated output, and/or minimum output.
- d) Measure the fuel temperature, fuel pressure, and integrated fuel input flow (in volume or in mass). Each measurement shall be taken at intervals of 60 s or less for a minimum of 3 h. If fuel is to be supplied intermittently, the data shall be collected for 20 times the interval of the fuel supply or 3 h, whichever is longer.

14.2.1.3 Calculation of results

14.2.1.3.1 Calculation of average gaseous fuel input rate

The average gaseous fuel input rate may be described either as the volumetric flow rate at reference conditions, q_{Vf0} in m³/s, or as the mass flow rate, q_{mf} in kg/s. It shall be calculated according to the following procedure:

a) Volumetric flow rate

- 1) The average volumetric flow rate of fuel under the test conditions, q_{Vf} in m³/s, shall be obtained by dividing the fuel volume measured over the test duration by the test duration.

$$q_{Vf} = \frac{V_f}{\Delta t} \quad (1)$$

where

q_{Vf} is the average volumetric flow rate of fuel under the test conditions (m³/s);

V_f is the fuel volume measured over the test duration (m³);

Δt is the test duration (s).

- 2) The average volumetric flow rate of fuel under the reference conditions, q_{Vf0} in m³/s, shall be calculated by the following equation. The average values of fuel temperature and pressure obtained during the test duration shall be used.

$$q_{Vf0} = q_{Vf} \cdot \frac{T_0}{T_f} \cdot \frac{p_f}{p_0} \quad (2)$$

where

q_{Vf0} is the average volumetric flow rate of fuel under reference conditions (m³/s);

q_{Vf} is the average volumetric flow rate of fuel under test conditions (m³/s);

T_0 is the reference temperature (288,15 K);

p_0 is the reference pressure (101,325 kPa (abs));

T_f is the average fuel temperature measured over the test duration (K);

p_f is the average fuel pressure measured over the test duration (kPa (abs)).

NOTE The pressure is absolute pressure.

b) Mass flow rate

The average mass flow rate of fuel under the test conditions, q_{mf} in kg/s, shall be obtained by dividing the fuel mass measured over the test duration by the test duration.

$$q_{mf} = \frac{m_f}{\Delta t} \quad (3)$$

where

q_{mf} is the average mass flow rate of fuel under the test conditions (kg/s);

m_f is the fuel mass measured over the test duration (kg);

Δt is the test duration (s).

14.2.1.3.2 Calculation of average gaseous fuel power input

The average gaseous fuel power input, P_{fin} in kJ/s, shall be calculated either for volumetric flow rate or for mass flow rate according to the following procedure.

a) Volumetric flow rate

- 1) The energy of fuel per unit volume at reference conditions, E_{Vf} in kJ/m³, shall be calculated by the following equation:

$$E_{Vf} = \frac{H_{f0}}{V_m} \quad (4)$$

where

- E_{Vf} is the energy input of the fuel per unit volume (kJ/m³);
- H_{f0} is the heating value of fuel on a molar basis under reference conditions (kJ/mol);
- V_m is the reference molar volume of ideal gas ($2,364\,5 \times 10^{-2}$ m³/mol) at reference conditions ($T_0 = 288,15$ K, $p_0 = 101,325$ kPa) (m³/mol).

where

the heating value of fuel, H_{f0} in kJ/mol under reference conditions, shall be calculated as follows:

$$H_{f0} = \sum_{j=1}^N x_j \cdot H_{f0j} \quad (5)$$

where

- H_{f0j} is the heating value of component j at reference temperature T_0 (kJ/mol);
- x_j is the molar ratio of component j ;
- j is a component of fuel;
- N is the number of fuel gas constituents.

NOTE 1 Numerical values of H_{f0j} are given in ISO 6974 and ISO 6975 and in Table A.1.

- 2) The average fuel power input, P_{fin} in kJ/s, shall be calculated with the following equation:

$$P_{fin} = q_{Vf0} \cdot E_{Vf} \quad (6)$$

where

- P_{fin} is the average fuel power input (kJ/s);
- q_{Vf0} is the average volumetric flow rate of fuel under reference conditions (m³/s);
- E_{Vf} is the energy input of the fuel per unit volume (kJ/m³).

NOTE 2 The specific enthalpy and pressure energy of gaseous fuel, which are considered in the calculation of fuel consumption energy in IEC 62282-3-200, are ignored in the calculation of fuel consumption energy described above because they are negligible values in small fuel cell power systems that are operated at low temperature and pressure.

b) Mass flow rate

- 1) The energy input of gaseous fuel per unit mass, E_{mf} in kJ/kg, shall be calculated with the following equation:

$$E_{mf} = \frac{H_{f0}}{M_f} \quad (7)$$

where

- E_{mf} is the energy input of gaseous fuel per unit mass (kJ/kg);
- H_{f0} is the heating value of fuel under reference conditions (kJ/mol);
- M_f is the molar mass of fuel (kg/mol), and is measured according to the methods detailed in ASTM F2602.

NOTE 3 The calculation of H_{f0} is described in “a) Volumetric flow rate” of 14.2.1.3.2.

- 2) The average fuel power input, P_{fin} in kJ/s, shall be calculated with the following equation:

$$P_{fin} = q_{mf} \cdot E_{mf} \quad (8)$$

where

- P_{fin} is the average gaseous fuel power input (kJ/s);
 E_{mf} is the energy input of gaseous fuel per unit mass (kJ/kg);
 q_{mf} is the average mass flow rate of fuel (kg/s).

14.2.2 Liquid fuel consumption test

14.2.2.1 General

This test is for measuring the liquid fuel input at rated electric power output. If operation at partial loads 50 %, 75 % and/or minimum power electric output are specified by the manufacturer, these operating points shall be measured as well.

This test shall be carried out concurrently with the electric power output test (14.3) and the heat recovery test (14.4).

14.2.2.2 Test method

- Operate the system at the rated electric power output for more than 30 min before starting the test.
- For systems including batteries, operate the system at rated electric power output for more than 30 min and until a known nominal state of charge of the battery is reached, before starting the test.
- Start the test while keeping the system operating at the rated electric power output. If such operation is specified by the manufacturer, repeat the test at partial loads 50 % and 75 % of rated output, and/or minimum output.
- Measure the mass of the fuel tank or of the entire system, including the fuel tank, at the start.
- Continue the test for a minimum of 3 h. If fuel is to be supplied intermittently, the total test duration shall be 20 times the interval of the fuel supply or 3 h, whichever is longer.
- Measure the mass of the fuel tank or of the entire system, including the fuel tank, at the end of the test.

14.2.2.3 Calculation of average liquid fuel power input

Total liquid fuel energy input over the test duration, E_{fin} in kJ, shall be calculated by the following equation:

$$E_{fin} = (A - B) \cdot H_{fl} \quad (9)$$

where

- E_{fin} is the total fuel energy input (kJ);
 A is the mass at the start of the test (kg);
 B is the mass at the end of the test (kg);
 H_{fl} is the heating value of the liquid fuel (kJ/kg).

Average fuel power input, P_{fin} in kJ/s, shall be calculated as follows:

$$P_{\text{fin}} = \frac{E_{\text{fin}}}{\Delta t} \quad (10)$$

where

P_{fin} is the average fuel power input (kJ/s);

E_{fin} is the total fuel energy input (kJ);

Δt is the test duration (s).

NOTE The heating value is measured according to the methods detailed in ASTM D4809-09.

14.3 Electric power output test

14.3.1 General

This test is for measuring the average net electric output at rated electric power output. If operation at partial loads 50 %, 75 % and/or minimum power electric output are specified by the manufacturer, these operating points shall be measured as well.

This test shall be carried out concurrently with the fuel consumption test (14.2) and the heat recovery test (14.4).

14.3.2 Test method

- Operate the system at the rated electric power output for more than 30 min before starting the test.
- For systems including batteries, operate the system at rated electric power output for more than 30 min and until a known nominal state of charge of the battery is reached, before starting the test.
- Start the test while keeping the system operating at the rated electric power output. If such operation is specified by the manufacturer, repeat the test at partial loads 50 % and 75 % of rated output, and/or minimum output.
- Measure the electric energy output and electric energy input over the test duration. The test shall be conducted for at least 3 h. If fuel is to be supplied intermittently, the total test duration shall be 20 times the interval of the fuel supply or 3 h, whichever is longer.

14.3.3 Calculation of average net electric power output

The average net electric power output shall be calculated by the following equation:

$$P_n = \frac{W_{\text{out}} - W_{\text{in}}}{\Delta t} \times 3\,600 \quad (11)$$

where

P_n is the average net electric power output (kW);

W_{out} is the electric energy output measured over the test duration (kW·h);

W_{in} is the electric energy input measured over the test duration (kW·h);

Δt is the test duration (s).

14.4 Heat recovery test

14.4.1 General

This test is for measuring the average recovered thermal power output at rated electric power output. If operation at partial loads 50 %, 75 % and/or minimum power electric output are specified by the manufacturer, these operating points shall be measured as well.

This test shall be carried out concurrently with the fuel consumption test (14.2) and the electric power output test (14.3).

For systems without utilization of the heat, the heat recovery test can be omitted.

14.4.2 Test method

- a) Operate the system at the rated electric power output for more than 30 min before starting the test.
- b) For systems including batteries, operate the system at rated electric power output for more than 30 min and until a known nominal state of charge of the battery is reached, before starting the test.
- c) Set the temperature of the returning fluid at a level appropriate for the recovered heat usage conditions. Control the amount of cooling fluid entering the thermal load to maintain the said conditions throughout the test.
- d) Start the test while keeping the system operating at the rated electric power output. If such operation is specified by the manufacturer, repeat the test at partial loads 50 % and 75 % of rated output, and/or minimum output.
- e) Measure the outgoing heat recovery fluid temperature at outlet, returning heat recovery fluid temperature at inlet, and integrated flow volume or mass at inlet or outlet. Each measurement shall be taken at intervals of 60 s or less for a minimum of 3 h. If fuel is to be supplied intermittently, the data shall be collected for 20 times the interval of the fuel supply or 3 h, whichever is longer. The outgoing heat recovery fluid temperature, the returning heat recovery fluid temperature, and the difference of their temperatures shall be reported.

14.4.3 Calculation of average recovered thermal power

The average recovered thermal power in kJ/s shall be calculated according to the following procedures:

a) Volumetric measurement

- 1) The average volumetric flow rate of heat recovery fluid, q_{VHR} in m³/s, shall be calculated by dividing the measured heat recovery fluid volume by the test duration.

$$q_{VHR} = \frac{V_{HR}}{\Delta t} \quad (12)$$

where

q_{VHR} is the average volumetric flow rate of heat recovery fluid measured over the test duration (m³/s);

V_{HR} is the measured volume of heat recovery fluid (m³);

Δt is the test duration (s).

- 2) The average recovered thermal power, P_{HR} in kJ/s, shall be calculated using the following equation. The average value of recovered fluid temperature obtained over the test duration shall be used.

$$P_{HR} = (T_{HR1} - T_{HR2}) \cdot q_{VHR} \cdot \rho_{HR} \cdot c_{HR} \quad (13)$$

where

P_{HR} is the average recovered thermal power over the test duration (kJ/s);

T_{HR1} is the average temperature of heat recovery fluid at outlet over the test duration (K);

- T_{HR2} is the average temperature of heat recovery fluid at inlet over the test duration (K);
- q_{VHR} is the average volumetric flow rate of heat recovery fluid over the test duration (m^3/s);
- ρ_{HR} is the density of heat recovery fluid at T_{HR1} (kg/m^3);
- c_{HR} is the specific heat capacity of heat recovery fluid at the temperature intermediate between T_{HR1} and T_{HR2} ($kJ/(kg \cdot K)$). If water is to be used as the heat recovery fluid, 4,186 $kJ/(kg \cdot K)$ shall be used for its specific heat capacity.

b) Mass measurement

- 1) The average mass flow rate, q_{mHR} in kg/s , shall be calculated by dividing measured heat recovery fluid mass by the test duration.

$$q_{mHR} = \frac{m_{HR}}{\Delta t} \quad (14)$$

where

- q_{mHR} is the average mass flow rate of heat recovery fluid (kg/s);
- m_{HR} is the measured heat recovery fluid mass (kg);
- Δt is the test duration (s).

- 2) The average recovered thermal power during the test duration, P_{HR} in kJ/s , shall be calculated using the following formula. The average value of recovered fluid temperature obtained over the test duration shall be used.

$$P_{HR} = (T_{HR1} - T_{HR2}) \cdot q_{mHR} \cdot c_{HR} \quad (15)$$

where

- P_{HR} is the average recovered thermal power over the test duration (kJ/s);
- T_{HR1} is the average temperature of heat recovery fluid at outlet over the test duration (K);
- T_{HR2} is the average temperature of heat recovery fluid at inlet over the test duration (K);
- q_{mHR} is the average mass flow rate of heat recovery fluid over the test duration (kg/s);
- c_{HR} is the specific heat capacity of heat recovery fluid at the temperature intermediate between T_{HR1} and T_{HR2} . If water is to be used as the heat recovery fluid, 4,186 $kJ/(kg \cdot K)$ shall be used for its specific heat capacity.

14.5 Start-up test

14.5.1 General

This test is for measuring the start-up time, and fuel and/or electric energy required for the start-up of a fuel cell power system.

For a system with a battery, the test for finding start-up fuel energy is not mandatory if the system is not equipped with the means to identify that the battery has reached a known nominal state of charge (refer to 11.3 b)).

14.5.2 Determination of state of charge of the battery

The time when the battery is recharged to the known nominal state of charge can be determined by either one of the following two methods.

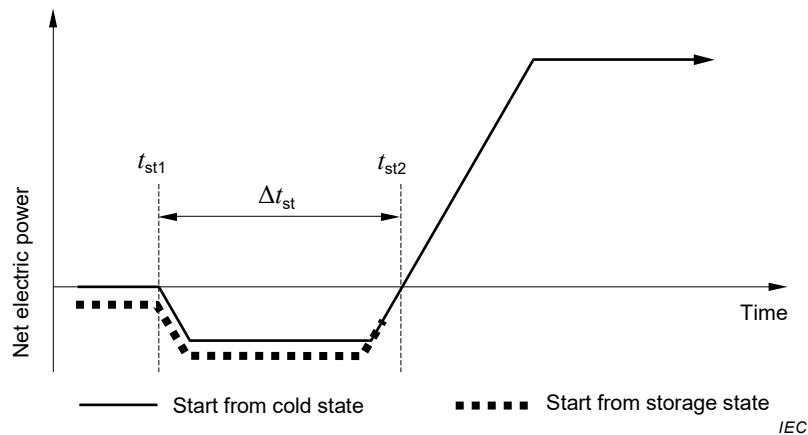
- a) For a system equipped with a means (for example, a display method or an output signal) to identify that the battery has reached a known nominal state of charge, the charge-out time is determined by that means (refer to 11.3 b)).
- b) For a system equipped with no means to identify that the battery has reached a known nominal state of charge, the charge-out time to reach the nominal state of charge may be determined by measuring the time when input fuel flow rate becomes stabilized within $\pm 2\%$ of the rated fuel flow rate after the fuel flow increase for recharging the battery ceases (see Figure 8). This measurement is not mandatory.

14.5.3 Test method

- a) Keep the system in cold state or storage state for a minimum of 48 h before starting the test.
- b) For a system with a battery, charge the battery to a known nominal state of charge then keep the system in a cold state or storage state for a minimum of 48 h before starting the test.
- c) Start the test. Measure the electric energy output, electric energy input, integrated fuel flow (or mass in the case of liquid fuel), fuel temperature, fuel pressure, and atmospheric pressure at intervals of 15 s or less.
- d) Initiate a start-up operation for the rated electric power output and record the time when the start-up action is commenced.
- e) For a system without a battery, record the time when the start-up action is completed.
- f) For a system with a battery, record the time when the start-up action is completed and the time when the battery is recharged to the known nominal state of charge.

NOTE 1 The initiation of a start-up is the time when the start-up button is pressed or the normal start-up signal is sent.

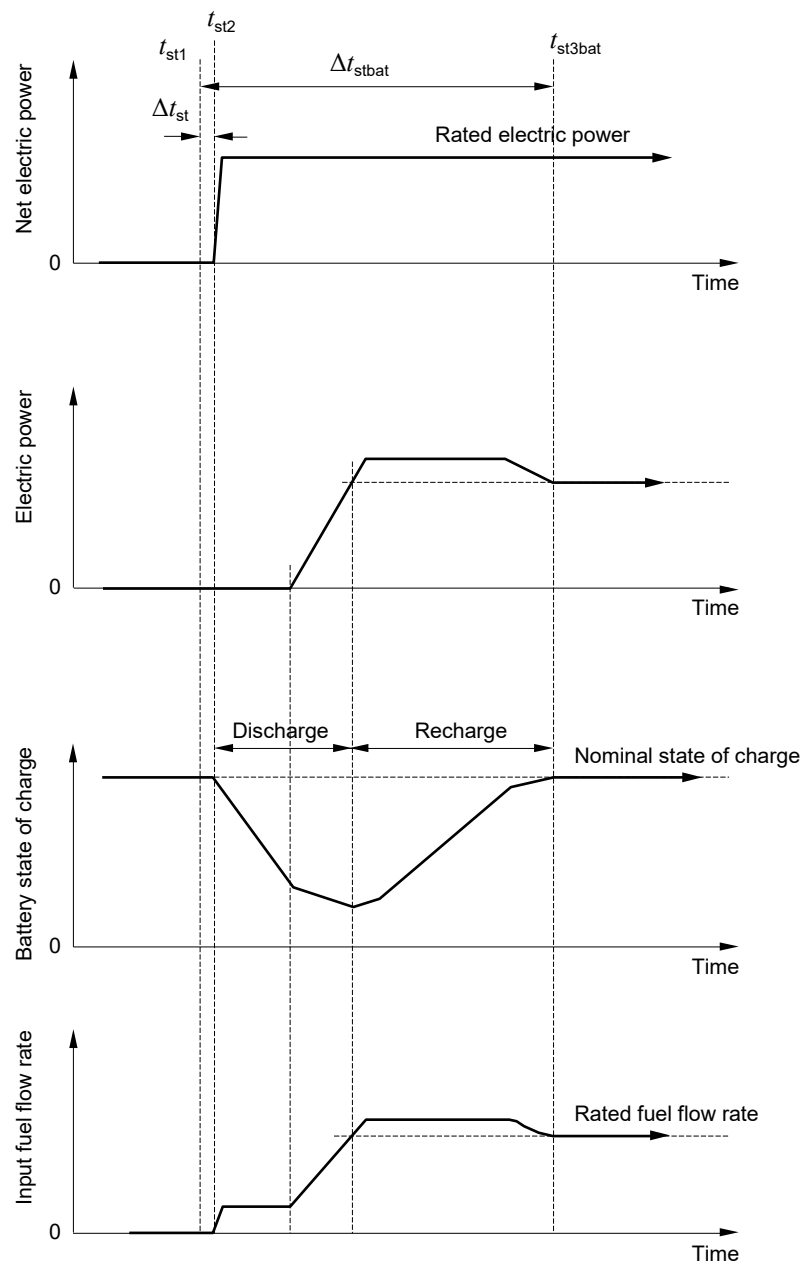
NOTE 2 The completion of a start-up is the time when the net electric power is generated as output.



Key

- Δt_{st} start-up time (s)
 t_{st1} start-up initiation time
 t_{st2} start-up completion time

Figure 7 – Example of electric power chart during start-up time for system without battery



IEC

Key

- t_{st1} start-up initiation time
- t_{st2} start-up completion time
- t_{st3bat} battery recharge completion time
- Δt_{st} start-up time (s)
- Δt_{stbat} duration from the start-up initiation to battery recharge completion (s)

Figure 8 – Example of electric power chart during start-up time for system with battery

14.5.4 Calculation of results

14.5.4.1 Calculation of start-up time

The start-up time shall be calculated using the following formula (refer to Figures 7 and 8):

$$\Delta t_{st} = t_{st2} - t_{st1} \quad (16)$$

where

Δt_{st} is the start-up time (s);

t_{st1} is the start-up initiation time;

t_{st2} is the start-up completion time.

14.5.4.2 Calculation of start-up energy

14.5.4.2.1 Calculation of fuel energy required during start-up time

a) For a system without a battery

For a fuel cell power system using gaseous fuel without a battery, the fuel energy input required during start-up time shall be calculated using the measured integrated fuel input over the start-up time. The calculation process is the same as that described in 14.2.1.3 for both volumetric flow and mass flow, integrated fuel input shall be used instead of average flow, which is used in Equations (1) to (8) in 14.2.1.3.

If non-inert purge gas or dilution gas containing chemical energy is fed into the system during start-up, the purge gas shall be considered as additional fuel. The energy content shall be added to the input, using the calculation method in 14.2.1.3.

For a fuel cell power system using liquid fuel without a battery, fuel energy required during start-up time shall be calculated using the measured mass of fuel tank or entire system at both the start-up initiation time and the start-up completion time using Equation (9). The calculation process is the same as that described in 14.2.2.3.

If only the mass of the fuel tank is measured and a fuel reservoir is included in the system, as in the example shown in Figure 9, the fuel reservoir shall be bypassed or relocated and weighed together with the fuel tank.

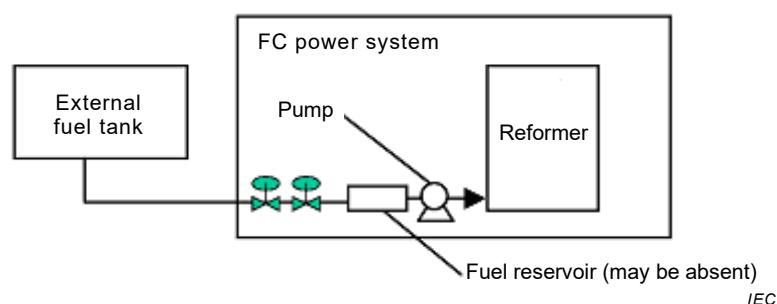


Figure 9 – Example of liquid fuel supply systems

b) For a system with a battery

For a fuel cell power system with a battery (equipped with a state-of-charge indicator), fuel energy required during start-up time, that is fuel energy for recharging the battery, shall be calculated using the following equation:

$$E_{finstbat} = E_{fin} - W_{output} \cdot \frac{100}{\eta_{el}} \times 3\,600 \quad (17)$$

where

$E_{finstbat}$ is the fuel energy required during start-up time for a system with a battery (kJ),

E_{fin}	is the fuel energy input over the duration from the start-up initiation time, t_{st1} , to the battery recharge completion time, t_{st3bat} (kJ);
W_{outbat}	is the electric energy output of the fuel cell power system over the duration from the start-up initiation time, t_{st1} , to the battery recharge completion time, t_{st3bat} (kW·h);
η_{el}	is the electrical efficiency (%) (refer to 14.10.2);
3 600	is the conversion factor from kW·h to kJ.

$W_{\text{outbat}} \cdot 100/\eta_{\text{el}} \times 3\,600$ is the fuel energy (kJ) consumed to produce W_{outbat} . For a fuel cell power system using liquid fuel, fuel energy input, E_{fin} , during start-up time, shall be calculated using the measured mass of the fuel tank or the entire system at start-up initiation time and its mass at battery recharge completion time. The calculation process is the same as for the case of a system without a battery.

NOTE 1 Direct measurement of the electric power supplying the battery charge circuit inside the system is not taken into account, because the performance tests in this document are carried out using physical quantities entering and leaving the fuel cell power system.

NOTE 2 Using the electrical efficiency η_{el} from steady-state performance tests in Equation (17) is an assumption. Actual electrical efficiency can differ during the start-up phase. Therefore, the result of this calculation can have increased uncertainties.

14.5.4.2.2 Calculation of electric energy required during start-up time

a) For a system without a battery

Electric energy required during start-up operation for the system without battery shall be calculated by the following equation:

$$W_{\text{inst}} = W_{\text{in}} - W_{\text{out}} \quad (18)$$

where

W_{inst}	is the electric energy required during start-up time for the system without a battery (kW·h);
W_{in}	is the electric energy input during start-up time, Δt_{st} (kW·h);
W_{out}	is the electric energy output during start-up time, Δt_{st} (kW·h).

b) For a system with a battery

Electric energy required during start-up operation for the system with battery shall be calculated by the following equation:

$$W_{\text{instbat}} = W_{\text{inbat}} - W_{\text{outbat}} \quad (19)$$

where

W_{instbat}	is the 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_{inbat}	is the 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_{outbat}	is the electric energy output over the duration from the start-up initiation time, t_{st1} , to the battery recharge completion time, t_{st3bat} (kW·h).

14.6 Ramp-up test

14.6.1 General

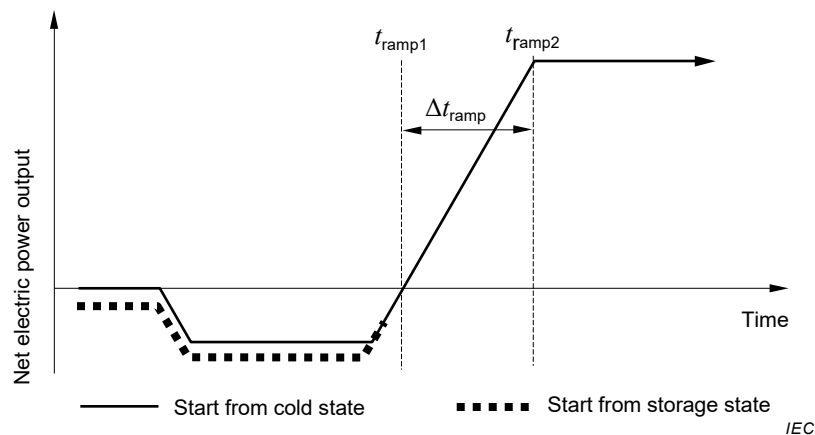
This test is for measuring the ramp-up time, and fuel and/or electric energy required for the ramping up of a fuel cell power system.

For systems with a battery, the ramp-up test does not apply since the phase of ramping up from positive net electric power output to rated net electric power output is already covered in the start-up test (see Figure 8).

14.6.2 Test method

- Conduct the start-up test according to 14.5.
- Record the time when the start-up action is completed and ramp-up starts.
- Continue to measure the electric energy output, electric energy input, integrated fuel flow (or mass in the case of liquid fuel), fuel temperature, fuel pressure, and atmospheric pressure at intervals of 15 s or less.
- Record the time when the ramp-up is completed.

NOTE 1 The completion of the ramp-up is the time when the rated net electric power output is reached.



Key

- Δt_{ramp} ramp-up time (s)
 t_{ramp1} ramp-up start time
 t_{ramp2} ramp-up completion time

Figure 10 – Example of electric power chart during ramp-up for system without battery

14.6.3 Calculation of results

14.6.3.1 Calculation of ramp-up time

The ramp-up time shall be calculated using the following formula (refer to Figure 10):

$$\Delta t_{\text{ramp}} = t_{\text{ramp2}} - t_{\text{ramp1}} \quad (20)$$

where

- Δt_{ramp} is the ramp-up time (s);
 t_{ramp1} is the ramp-up start time;
 t_{ramp2} is the ramp-up completion time.

14.6.3.2 Calculation of ramp-up energy

14.6.3.2.1 Calculation of fuel energy required during ramp-up time

Calculate the fuel energy required during ramp-up time using the same approach as described for the energy required during start-up time for systems without a battery, as described in 14.5.4.2.1 a).

Use the ramp-up time, ramp-up start time and ramp-up completion time as applicable.

14.6.3.2.2 Calculation of net electric energy output during ramp-up time

The net electric energy output during ramp-up time shall be calculated with the following formula:

$$W_{\text{outramp}} = W_{\text{out}} - W_{\text{in}} \quad (21)$$

where

W_{outramp} is the net electric energy output during ramp-up time (kW·h);

W_{in} is the electric energy input during ramp-up time, Δt_{ramp} (kW·h);

W_{out} is the electric energy output during ramp-up time, Δt_{ramp} (kW·h).

14.7 Storage state test

14.7.1 General

This test is for measuring electric power input in storage state for those systems which have a heater or similar for maintaining catalyst performance and/or a control system for monitoring and maintaining the storage state conditions.

If the electric energy is supplied from the integrated battery in the system, this energy is ignored because it cannot be measured outside the system.

14.7.2 Test method

- Keep the system in storage state.
- Measure the electric energy input and the duration from the initiation to the end of the test. The test duration shall be at least 3 h.

14.7.3 Calculation of average electric power input in storage state

Average electric power input in storage state shall be calculated with the following equation:

$$P_{\text{instore}} = \frac{W_{\text{instore}}}{\Delta t} \times 3\,600 \quad (22)$$

where

P_{instore} is the average electric power input in storage state (kW);

W_{instore} is the electric energy input at storage state from the initiation to the end of test (kW·h);

Δt is the test duration (s).

14.8 Electric power output change test

14.8.1 General

This test is for evaluating the changeability of the electric power output of fuel cell power systems. The electric power output is to be changed between the rated output and minimum output. The rated and minimum electric power outputs are specified by the manufacturer.

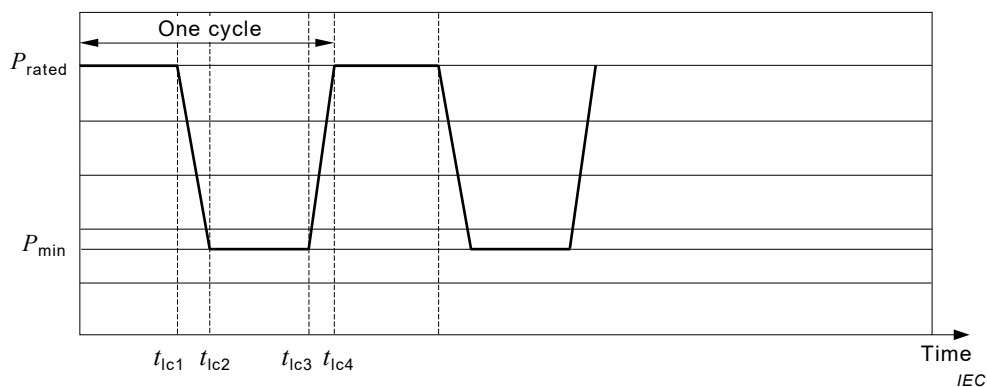
14.8.2 Test method

- Operate the system at the rated electric power output for more than 30 min before starting the test.

For systems that include batteries, operate the system at its rated electric power output for more than 30 min and until a known nominal state of charge of the battery is reached before starting the test.

- b) Start the test by continuing to operate the system at the rated electric power output for more than 1 h.
- c) Measure the electric power output at intervals of 1 s or less until the completion of the test. For systems that include batteries, a high-speed voltage recorder such as an oscilloscope is required for measuring the increase rate of electric power because the rate is extremely rapid in general (in the order of milliseconds).
- d) Set the target change value of electric power output at the minimum electric power output, initiate an electric power output decreasing action and record the start time of the electric power output decreasing action (see Figure 11 and Figure 12).
- e) Record the time when the electric power output reaches the minimum electric power output within $\pm 2\%$ of rated power output (see Figure 13).
- f) Maintain the electric power output at the minimum electric power output for a minimum of 1 h.
- g) Set the target change value of the electric power output to the rated electric power output, initiate the increasing electric power output action and record the start time of the increasing electric power output action (see Figure 11 and Figure 12).
- h) Record the time when the electric power output reaches the rated electric power output within $\pm 2\%$ of the rated power output (see Figure 13).
- i) Maintain the electric power output at the rated electric power output for a minimum of 1 h.
- j) Repeat steps d) to i) for three cycles at least.

This test may be started with an increasing electric power output action.



Key (for Figures 11, 12 and 13)

P_{rated}	rated electric power output
P_{min}	minimum electric power output
t_{lc1}	start time of decreasing electric power output action
t_{lc2}	time when the electric power output reaches the minimum electric power output within $\pm 2\%$ of rated electric power output (see Figure 13)
t_{lc3}	start time of electric power output increasing action
t_{lc4}	time when the electric power output reaches the rated electric power output within $\pm 2\%$ of rated electric power output (see Figure 13)

**Figure 11 – Electric power output change pattern
for system without battery**

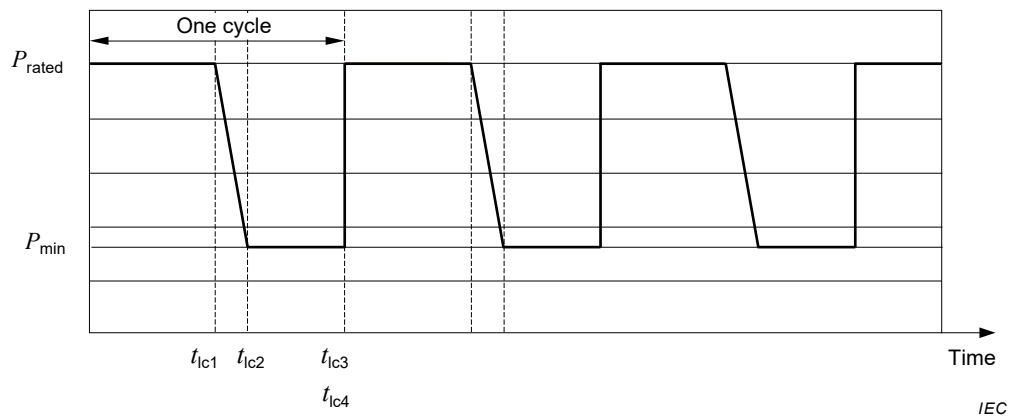


Figure 12 – Electric power output change pattern for system with battery

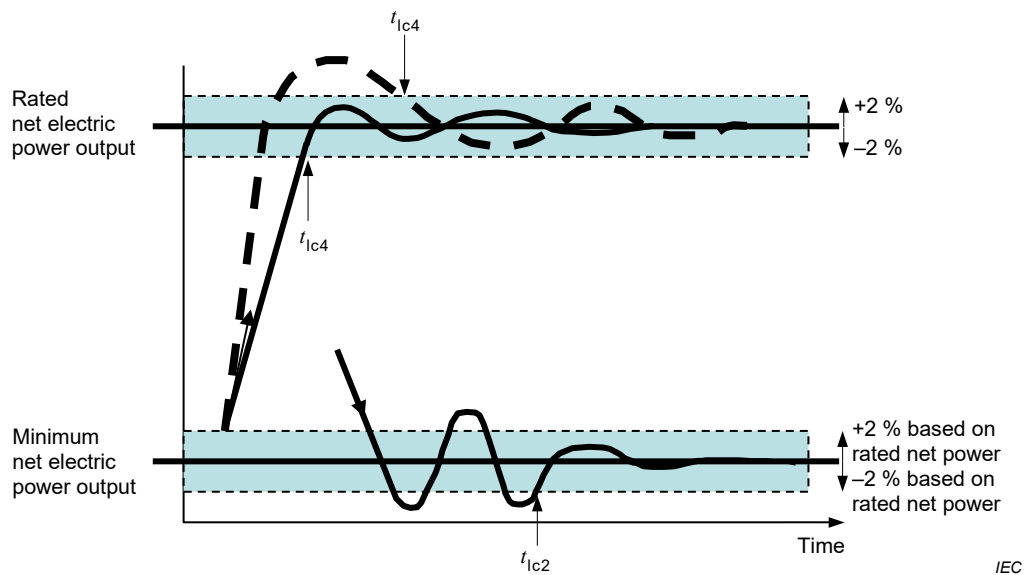


Figure 13 – Example for electric power change stabilization criteria

14.8.3 Calculation of electric power output change rate

The rates of decrease and increase of electric power output shall be calculated with the following equations:

$$dP_{\text{down}} = \frac{P_d}{\Delta t_{\text{lcdown}}} \quad (23)$$

$$dP_{\text{up}} = \frac{P_d}{\Delta t_{\text{lcup}}} \quad (24)$$

where

dP_{down} is the decrease rate of electric power output (kW/s);

dP_{up} is the increase rate of electric power output (kW/s);

P_d is the electric power output change range between P_{rated} and P_{min} (kW);

Δt_{Icdown} is the duration of the decrease in electric power output from t_{Ic1} to t_{Ic2} (s);

Δt_{Icup} is the duration of the increase in electric power output from t_{Ic3} to t_{Ic4} (s).

The rates of decrease and increase in the electric power output shall be the averages taken over three cycles.

14.9 Shutdown test

14.9.1 General

This test is for measuring the shutdown time, and fuel and/or electric energy required for the shutdown of a fuel cell power system.

The definition of shutdown time is the same for a system without a battery and a system with a battery. The shutdown time is defined as the duration required for transitioning from rated electric power output to storage state.

The definition of shutdown energy is the same for a system without a battery and a system with a battery. The shutdown energy is the energy supplied from outside the system for shutdown during the shutdown time. The electric energy during shutdown time from the integrated battery is ignored because it cannot usually be measured outside the system (refer to Figure 2).

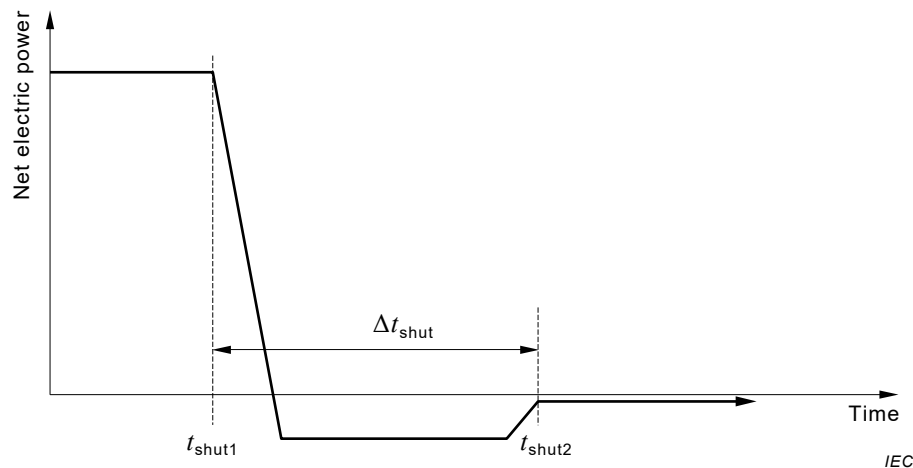
14.9.2 Test method

- a) Operate the system at the rated electric power output for more than 30 min before starting the test.
- b) For systems that include batteries, operate the system at its rated electric power output for more than 30 min and until the known nominal state of charge of the battery is reached before starting the test.
- c) Start the test. Measure the electric power output, electric power input, electric energy output, electric energy input, integrated fuel input (in volume or in mass), fuel temperature, fuel pressure, and atmospheric pressure at intervals of 15 s or less until the completion of the test. For systems using liquid fuel, the fuel pressure and atmospheric pressure are not required.
- d) Initiate a normal shutdown action and record the start time of the shutdown action.
- e) When the normal shutdown action is completed, record the completion time.

NOTE 1 The start time of a shutdown action is when the shutdown button is pressed or the normal shutdown signal is sent.

NOTE 2 The completion time of a shutdown action is when the net electric power output of the system becomes less than 150 % of the value at the storage state.

The net electric power output of the system at storage state is the net electric power output of the system immediately before initiating the start-up action of the system. When necessary, check the value of the net electric power output of the system at the storage state before this test with the heater off (if a heater is used).



Key

Δt_{shut}	shutdown time (s)
t_{shut1}	shutdown initiation time
t_{shut2}	shutdown completion time

Figure 14 – Electric power chart during shutdown time

14.9.3 Calculation of results

14.9.3.1 Calculation of shutdown time

Normal shutdown time shall be calculated with the following equation (refer to Figure 14):

$$\Delta t_{\text{shut}} = t_{\text{shut2}} - t_{\text{shut1}} \quad (25)$$

where

- Δt_{shut} is the shutdown time (s);
- t_{shut1} is the shutdown initiation time;
- t_{shut2} is the shutdown completion time.

14.9.3.2 Calculation of shutdown energy

14.9.3.2.1 Fuel energy required during shutdown time

For a fuel cell power system using gaseous fuel, the fuel energy input required during shutdown time shall be calculated using the measured integrated fuel input over the shutdown time. The calculation process is the same as that described in 14.2.1.3 for both volumetric flow and mass flow. Integrated fuel input shall be used instead of average flow, which is used in Equations (1) to (8) in 14.2.1.3.

For fuel cell power systems using liquid fuel, fuel energy input during shutdown time shall be calculated using the measured mass of the fuel tank or the entire system at both the shutdown initiation time and the shutdown completion time using Equation (9).

If only the mass of the fuel tank is measured and a fuel reservoir is included in the system, as in the example shown in Figure 9, the fuel reservoir shall be bypassed or relocated and weighed together with the fuel tank.

14.9.3.2.2 Electric energy input during shutdown time

Electric energy input during shutdown time shall be calculated with the following equation: