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Functions concerned
Fonctions concernées

☐ Safety Sécurité	☐ EMC CEM	☐ Environment Environnement	☐ Quality assurance Assurance de la qualité

INTERNATIONAL ELECTROTECHNICAL COMMISSION — COMMISSION ÉLECTROTECHNIQUE INTERNATIONALE

Title

FUEL CELL TECHNOLOGIES - Part 3-2: Stationary fuel cell power plants - Performance test methods

Titre

TECHNOLOGIE DES PILES À COMBUSTIBLE - Partie 3-2: Systèmes à piles à combustible stationnaires - Méthodes d'essai des performances

ATTENTION
VOTE PARALLÈLE
CEI – CENELEC
L'attention des Comités nationaux de la CEI, membres du CENELEC, est attirée sur le fait que ce projet finale de Norme internationale est soumis au vote parallèle.
Un bulletin de vote séparé pour le vote CENELEC leur sera envoyé par le Secrétariat Central du CENELEC.

ATTENTION
IEC – CENELEC
PARALLEL VOTING
The attention of IEC National Committees, members of CENELEC, is drawn to the fact that this final draft International Standard (DIS) is submitted for parallel voting.
A separate form for CENELEC voting will be sent to them by the CENELEC Central Secretariat.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

FUEL CELL TECHNOLOGIES –

Part 3-2: Stationary fuel cell power plants – Performance test methods

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 62282-3-2 has been prepared by IEC technical committee 105: Fuel cell technologies.

The text of this standard is based on the following documents:

FDIS	Report on voting
105/XX/FDIS	105/XX/RVD

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

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

IEC 62282 consists of the following parts under the general title *Fuel cell technologies*:

Part 1: Terminology

Part 2: Fuel cell modules

Part 3-1: Stationary fuel cell power plants – Safety (under consideration)

Part 3-2: Stationary fuel cell power plants – Performance test methods

Part 3-3: Stationary fuel cell power plants – Installation (under consideration)

Part 4: Fuel cell systems for propulsion and auxiliary power units (under consideration)

Part 5: Portable fuel cell appliances – Safety and performance requirements (under consideration)

Part 6-1: Micro fuel cell power systems – Safety (under consideration)

Part 6-2: Micro fuel cell power systems – Performance (under consideration)

Part 6-3: Micro fuel cell power systems – Interchangeability (under consideration)

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date[1] indicated on the IEC web site under "http://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.

[1)] The National Committees are requested to note that for this publication the maintenance result date is 2007.

INTRODUCTION

This part of IEC 62282 describes how to measure the performance of stationary fuel cell power systems for residential, commercial, agricultural and industrial applications. The following fuel cell types have been considered: Alkaline Fuel Cells (AFC), Phosphoric Acid Fuel Cells (PAFC), Polymer Electrolyte Fuel Cells (PEFC), Molten Carbonate Fuel Cells (MCFC) and Solid Oxide Fuel Cells (SOFC).

FUEL CELL TECHNOLOGIES –

Part 3-2: Stationary fuel cell power plants – Performance test methods

1 Scope

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

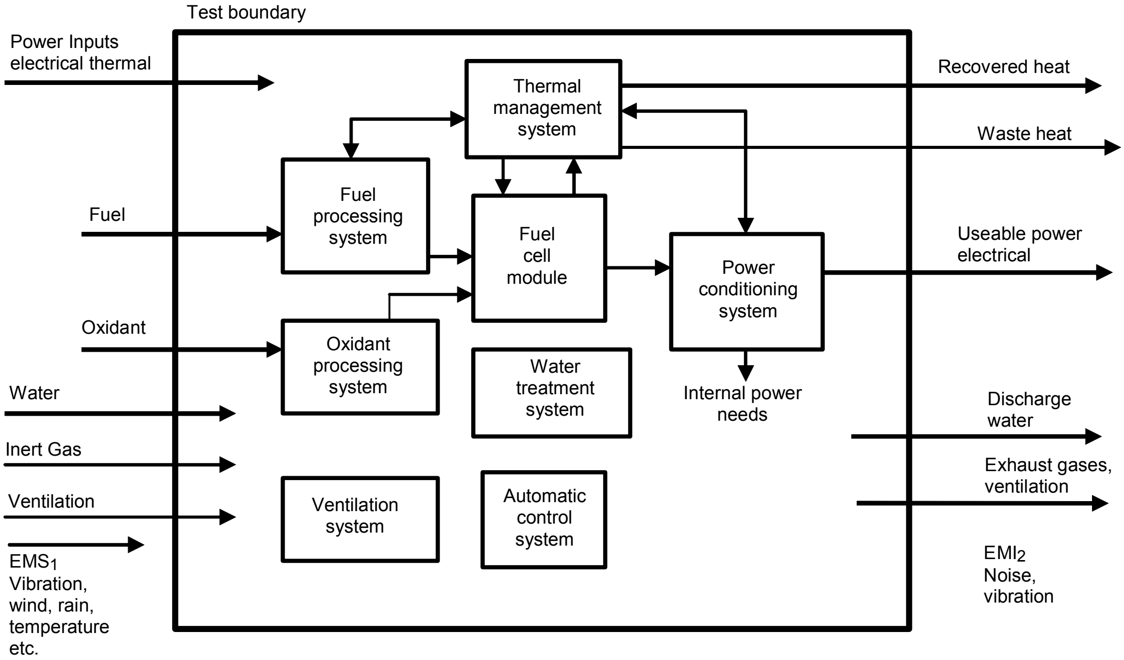
- power output under specified operating and transient conditions;
- electrical and thermal efficiency under specified operating conditions;
- environmental characteristics; for example, gas emissions, noise, etc. under specified operating and transient conditions.

Coverage for Electromagnetic Compatibility (EMC) is not provided in this part of IEC 62282.

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

- All energy recovery systems are included within the test boundary.
- Calculation of the heating value of the input fuel (such as natural gas, propane gas, and pure hydrogen gas, etc.) is based on the conditions of the fuel at the boundary of the fuel cell power system.

This standard does not take into account mechanical (shaft) power or mechanical energy inputs or outputs. Mechanical systems required for fuel cell operation (i.e. ventilation or micro-turbines or compressors) will be included inside the test boundary. The direct measurement of these mechanical systems inside the test boundary is not required; however, their effects will be included in the fuel cell power system operation. If mechanical (shaft) power and energy cross the test boundary, additional measurements and calculations are necessary.



Key

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

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

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

[1] EMS: Electromagnetic Susceptibility

[2] Electromagnetic Interference

Figure 1 – Fuel cell power system diagram

2 Normative references

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

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

IEC 60359:2001, *Electrical and electronic equipment – Expression of performance*

IEC 60688:1992, *Electrical measuring transducers for converting a.c. electrical quantities to analogue or digital signals*

IEC 61000-4-7, *Electromagnetic compatibility (EMC) – Part 4-7: Testing and measurement techniques – General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto*

IEC 61000-4-13, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*

IEC 61028:1991, *Electrical measuring instruments – X-Y recorders*

IEC 61143 (all parts), *Electrical measuring instruments – X-t recorders*

IEC 61672-1, *Electroacoustics – Sound level meters – Part 1: Specifications*

IEC 61672-2, *Electroacoustics – Sound level meters – Part 2: Pattern evaluation tests*

IEC 62052-11, *Electricity metering equipment (AC) – General requirements, tests and test conditions – Part 11: Metering equipment*

IEC 62053-22, *Electricity metering equipment (a.c.) – Particular Requirements – Part 22: Static meters for active energy (classes 0,2 S and 0,5 S)*

ISO 3648, *Aviation fuels – Estimation of net specific energy*

ISO 3744:1994, *Acoustics – Determination of sound power levels of noise sources using sound pressure – Engineering method in an essentially free field over a reflecting plane*

ISO 4677-1, *Atmospheres for conditioning and testing – Determination of relative humidity – Part 1: Aspirated psychrometer method*

ISO 4677-2, *Atmospheres for conditioning and testing – Determination of relative humidity – Part 2: Whirling psychrometer method*

ISO 5167 (all parts), *Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full*

ISO 5348, *Mechanical vibration and shock – Mechanical mounting of accelerometers*

ISO 6060, *Water quality – Determination of the chemical oxygen demand*

ISO 6326 (all parts), *Natural gas − Determination of sulfur compounds*

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

ISO 6975 (all parts), *Natural gas − Extended analysis – Gas-Chromatographic method*

ISO 6976, *Natural gas – Calculation of calorific values, density, relative density and Wobbe index from composition*

ISO 7934, *Stationary source emissions – Determination of the mass concentration of sulfur dioxide – Hydrogen peroxide/barium perchlorate/thorin method*

ISO 7935, *Stationary source emissions – Determination of the mass concentration of sulfur dioxide – Performance characteristics of automated measuring methods*

ISO 8217, *Petroleum products – Fuel (class F) – Specifications of marine fuels*

ISO 9096, *Stationary source emissions – Manual determination of mass concentration of particulate matter*

ISO 10101 (all parts), *Natural gas* − *Determination of water by the Karl Fisher Method*

ISO 10396, *Stationary source emissions – Sampling for the automated determination of gas concentrations*

ISO 10523, *Water quality – Determination of pH*

ISO 10707, *Water quality – Evaluation in an aqueous medium of the "ultimate" aerobic biodegradability of organic compounds – Method by analysis of biochemical oxygen demand (closed bottle test)*

ISO 10780, *Stationary source emissions – Measurement of velocity and volume flowrate of gas streams in ducts*

ISO 10849, *Stationary source emissions – Determination of the mass concentration of nitrogen oxides – Performance characteristics of automated measuring systems*

ISO 11042-1, *Gas turbines – Exhaust gas emission – Part 1: Measurement and evaluation*

ISO 11042-2, *Gas turbines – Exhaust gas emission – Part 2: Automated emission monitoring*

ISO 11541, *Natural gas – Determination of water content at high pressure*

ISO 11564, *Stationary source emissions – Determination of the mass concentration of nitrogen oxides – Naphthylethylenediamine photometric method*

ISO 14687: 1999, *Hydrogen fuel – Product specification*

ISO 16622, *Meteorology – Sonic anemometer/thermometers – Acceptance test methods for mean wind measurements*

ASTM D4809-00, *Standard Test Method for Heat of Combustion of Liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method)*

3 Terms, definitions and symbols

3.1 Terms and definitions

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

3.1.1
fuel cell power system
system which electrochemically converts chemical energy to electrical energy (direct current or alternating current electricity) and thermal energy

NOTE The fuel cell power system is composed of all or some of the following subsystems: one or more fuel cell modules, a fuel processing system, a power conditioning system, a thermal management system, and other subsystems needed. A generic fuel cell power system is shown in Figure 1.

3.1.2
interface point
measurement point at the boundary of a fuel cell power system at which material and/or energy either enters or leaves

NOTE 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 1) to be assessed should be determined by agreement of the parties.

3.1.3
parasitic load
power required for auxiliary machines, control systems and equipment necessary to operate a fuel cell power system

3.1.4
fuel consumption
amount of natural gas, hydrogen, methanol, liquid petroleum gas, propane, butane, or other energy source material consumed by the fuel cell power system during specified operating conditions

3.1.5
oxidant consumption
amount of oxygen consumed inside the fuel cell module during specified operating conditions

3.1.6
electrical efficiency (of a fuel cell power system)
ratio of net electric output power of a fuel-cell power system at a given instant to the total power of the fuel and oxidant fed to the same fuel-cell power system at the same instant

NOTE If electrical power is supplied to a parasitic load of a fuel cell power system from an external source, this electrical power is deducted from the electrical power output of the fuel cell power system.

3.1.7
recovered heat (of a fuel cell power system)
thermal energy recuperated from the fuel cell power system

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

3.1.8
heat recovery efficiency (of a fuel cell power system)
ratio of thermal power recovered at a given instant from a fuel cell power system to the total power of the fuel and oxidant at the same instant

3.1.9
overall energy efficiency (of fuel cell power system)
sum of the electrical efficiency and heat recovery efficiency

3.1.10
cold state
condition of a fuel cell power system at ambient temperature with no power input or output

3.1.11
storage state
fuel cell power system which is non-operational and possibly requiring, under conditions specified by the manufacturer, the input of thermal or electrical energy in order to prevent deterioration of the components

3.1.12
standby state
fuel cell power system which is at operating temperature and in an operational mode from which the fuel cell power system is capable of being promptly switched to an operational mode with net electrical power output

3.1.13
start-up time
duration required for the transition from cold state to net electrical power output for systems that do not require external power to maintain a storage state. For systems that require external power to maintain a storage state, this is the duration required for transitioning from storage state to net electrical power output

3.1.14
shutdown time
duration between the instant when the load is removed at rated power and the instant when the shutdown is completed as specified by the manufacturer

NOTE The shutdown operation is classified into types: normal shutdown and emergency shutdown.

3.1.15
power response time
duration between the instant of initiating a change of electrical or thermal power output and when the electrical or thermal output power attains the steady state set value within tolerance

3.1.16
90 % power response time
duration between the instant of initiating a change of electrical or thermal power output and when the electrical or thermal output power attains 90 % of the desired value

3.1.17
response time to rated power
duration between the instant when the step load change to rated power is initiated and the first instant when this value is delivered

3.1.18
start-up energy
sum of electrical, thermal, and/or chemical (fuel) energy required during the start-up time

3.1.19
emission characteristics
concentrations of total sulfur oxides (SO_x), total nitrogen oxides (NO_x), carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbon compounds and particulate in the exhaust gas

NOTE Measured at the point of discharge to the environment as described in the present part of IEC 62282.

3.1.20
audible noise level
sound pressure level produced by the fuel cell power system measured at a specified distance in all operation modes

NOTE Expressed as decibels (dB) and measured as described in this document.

3.1.21
background noise level
sound pressure level of ambient noise at the measurement point

NOTE This measurement is taken as described in this document with the fuel cell power system in the cold state.

3.1.22
vibration level
maximum measurement value of mechanical oscillations produced by the fuel cell power system during operation

NOTE This is a value expressed as decibels (dB) as described in this document.

3.1.23
background vibration level
mechanical oscillations caused by the environment that affect vibration level readings

NOTE Background vibration is measured with the fuel cell power system in the cold state.

3.1.24
discharge water
water that is discharged from the fuel cell power system

NOTE Discharge water does not constitute part of a thermal recovery system.

3.1.25
water consumption
water supplied (from outside the test boundary) to the power system other than initial fill

3.1.26
waste heat
thermal energy released and not recovered

3.1.27
test run
time period when data points required for the computation of test results are recorded

NOTE Reported results are computed based on these data points.

3.1.28
purge gas consumption
amount of inert gas or dilution gas supplied to the fuel cell power system during specific conditions to make it ready for operation or shutdown

3.2 Symbols

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

Table 1 – Symbols

Symbol	Definition	Unit
q_V	**Volumetric flow rate**	
q_{vf}	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m^3/s
q_{vf0}	Volumetric flow rate of fuel at the reference conditions	m^3/s
q_{ve}	Volumetric flow rate of exhaust gas at exhaust gas temperature and pressure	m^3/s
q_{va}	Volumetric flow rate of air at temperature t_a and pressure p_a	m^3/s
q_{va0}	Volumetric flow rate of air at the reference conditions	m^3/s
q_{vw}	Volumetric flow rate of water at process temperature and pressure	m^3/s
q_m	**Mass flow rate**	
q_{mf}	Mass flow rate of fuel	kg/s
q_{ma}	Mass flow rate of air	kg/s
q_{mHR1}	Mass flow rate of heat recovery fluid at the interface point of fluid output	kg/s
q_{mHR2}	Mass flow rate of heat recovery fluid at the interface point of fluid input (return stream to the fuel cell power system)	kg/s
q_{me}	Mass flow rate of emission	kg/s
P	**Electrical power**	
P_{out}	Active power of electrical power output (including direct current)	W, kW
P_{in}	Active power of electrical power input from external power source(s) (including direct current)	W, kW
p	**Pressure**	
p_0	Reference pressure	kPa
p_f	Pressure of fuel	kPa
p_a	Pressure of oxidant (air)	kPa
p_{HP1}	Pressure of heat recovery fluid output	kPa
p_{HR2}	Pressure of heat recovery fluid input	kPa
t	**Temperature**	
t_0	Reference temperature	K
t_f	Temperature of fuel	K
t_a	Temperature of oxidant (air)	K
t_{HR1}	Temperature of heat recovery fluid output	K
t_{HR2}	Temperature of heat recovery fluid input	K
ρ	**Density**	
ρ_{f0}	Density of fuel at the reference conditions	kg/m^3
ρ_f	Density of liquid fuel at temperature t_f	kg/m^3
ρ_{a0}	Density of oxidant (air) at the reference conditions	kg/m^3
ρ_e	Mass concentration of emissions at exhaust gas temperature and pressure	kg/m^3
x_j	Molar ratio of component j	--

Symbol	Definition	Unit
$\boldsymbol{Q}$	**Heating value**	
Q_{HR}	Value of recovered thermal energy	kJ/s
Q_{fo}	Heating value of fuel at the reference conditions	kJ/mol
Q_{fl}	Heating value of fuel at liquid phase	kJ/kg
Q_{f0j}	Heating value of component j	kJ/mol
Q_{WH}	Waste heat	kJ/s
$\boldsymbol{H,h}$	**Enthalpy, specific enthalpy**	
h_{HR1}	Enthalpy of heat recovery fluid output	kJ
h_{HR2}	Enthalpy of heat recovery fluid input	kJ
h_{HR1}	Specific enthalpy of heat recovery fluid at temperature t_{HR1} and at pressure p_{HR1}	kJ/kg
h_{HR2}	Specific enthalpy of heat recovery fluid at temperature t_{HR2} and at pressure p_{HR2}	kJ/kg
h_f	Specific enthalpy of fuel at temperature t_f	kJ/mol
h_{fo}	Specific enthalpy of fuel at the reference temperature	kJ/mol
h_a	Specific enthalpy of oxidant (air) at temperature t_f	kJ/mol
h_{ao}	Specific enthalpy of oxidant (air) at the reference temperature	kJ/mol
$\boldsymbol{E}$	**Input energy and power**	
E_{fv}	Input energy of the fuel	kJ/m³
E_{pf}	Pressure energy of the fuel	kJ/mol
E_{av}	Input energy of the oxidant (air)	kJ/m³
E_{pa}	Pressure energy of the oxidant (air)	kJ/mol
Q_{in}	Input total power supplied by fuel and oxidant	kJ/s
$\boldsymbol{\eta}$	**Efficiency**	
η_e	Electrical efficiency	%
η_{th}	Heat recovery efficiency	%
η_{total}	Overall energy efficiency	%
$\boldsymbol{V}$	**Voltage**	
V_{out}	Voltage of electrical power output	V, kV
V_{in}	Voltage of electrical power input	V, kV
$\boldsymbol{I}$	**Current**	
I_{out}	Current of electrical power output	A
I_{in}	Current of electrical power input	A
$\boldsymbol{\lambda}$	**Power factor**	
λ_{out}	Power factor of electrical power output	--
λ_{in}	Power factor of electrical power input	--
$\boldsymbol{T,PR,QR}$	**Response time, Ramp rate**	
T_{up}	– Response time required from minimum power to rated power – Response time required from minimum thermal power to rated thermal power	s
T_{down}	– Response time required from rated power to minimum power – Response time required from rated thermal power to minimum thermal power	s

Symbol	Definition	Unit
T_{up90}	– Response time required until when power reaches 90 % of the specified upper demand value – Response time required until when thermal power reaches 90 % of the specified upper demand value	s
T_{down90}	– Response time required until when power reaches 90 % of the specified lower demand value – Response time required until when thermal power reaches 90 % of the specified lower demand value	s
PR_{rated}	Ramp rate from minimum to rated power	W/s, kW/s
PR_{min}	Ramp rate from rated to minimum power	W/s, kW/s
PR_{up90}	Ramp rate from minimum electrical power to 90 % of rated electrical power	W/s, kW/s
PR_{down90}	Ramp rate from rated electrical power to a power level corresponding to 90 % of the total downward difference between rated power and minimum power	W/s, kW/s
QR_{rated}	Ramp rate from minimum thermal power to rated thermal power	kJ/s/s, W/s, kW/s
QR_{min}	Ramp rate from rated thermal power to minimum thermal power	kJ/s/s, W/s, kW/s
QR_{up90}	Ramp rate from minimum thermal power to 90 % of rated thermal power	kJ/s/s, W/s, kW/s
QR_{down90}	Ramp rate from rated thermal power to a thermal power level corresponding to 90 % of the total downward difference between rated thermal power and minimum thermal power	kJ/s/s, W/s, kW/s
NOTE Main symbols in the fuel cell power system correspond to Figure 2.		

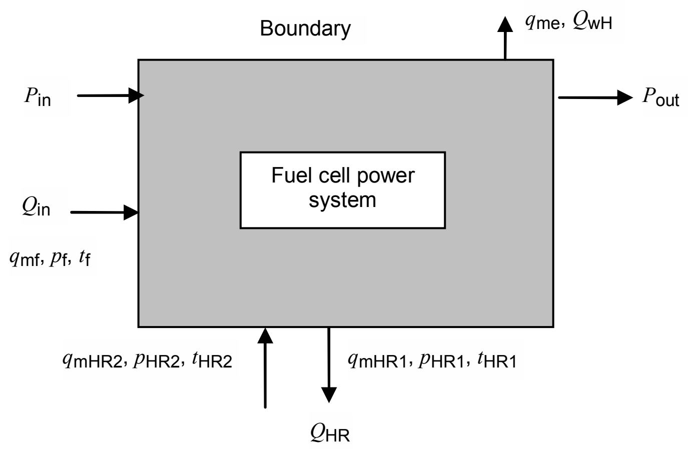


Figure 2 – Symbol diagram

4 Reference conditions

4.1 General

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

4.2 Temperature and pressure

The reference conditions are specified as follows:

Reference temperature: t_0 = 288,15 K (15 °C)

Reference pressure: p_0 = 101,325 kPa

4.3 Heating value base

Heating value of fuel is based on LHV in principle.

$$\eta_e \text{ or } \eta_{th} = XX\ \%$$

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

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

$$\eta_e \text{ or } \eta_{th} = XX\ \%\ (HHV)$$

NOTE LHV is the Lower Heating Value; HHV is the Higher Heating Value.

5 Performance and classes of tests

5.1 Performance tests

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

a) Operation: to test the performance of the system during normal operation or during an operational transient.

b) Environmental aspects: to test how the system affects the environment.

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

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

5.2 Classes of tests

There are in general three categories of tests as defined by the International Electrotechnical Vocabulary (IEV). However additional explanations are provided as follows, to provide clarification.

a) Type test

A test of one or more devices made to a certain design to show that the design meets certain specifications.

NOTE 1 Type tests are mandatory. They must be performed on a representative number of fuel cell power systems, each one considered as a whole. The purpose is to verify the compliance of the design with the selected requirements.

b) Routine test

A test to which each individual device is subjected during and/or after manufacture to ascertain whether it complies with certain criteria.

NOTE 2 No routine performance tests are required or necessary or identified in this document.

c) Acceptance test

A contractual test to prove to the customer that the device meets certain conditions of its specification.

NOTE 3 Acceptance tests, agreed between the manufacturer and the user and according to the specifications of the user, may be selected from the items listed in Table 2. When such tests are selected, they must be performed according to this document.

NOTE 4 Type tests and routine tests are generally performed in the same way and by using the same procedure. Differences between type tests and routine tests may be necessary, in the event that routine tests are done (for example, the strictest stability requirements may not be necessary or the number of measurements taken may be less for routine tests). These differences will be explained in the description of the test method.

NOTE 5 This document describes test methods only; no performance targets are set.

Table 2 – Test item and test classification

Item	Test	Type test	Routine test
	Operation		
1	Electrical power output	x	
2	Total harmonic distortion	x	
3	Fuel consumption	x	
4	Oxidant consumption	x	
5	Electrical efficiency	x	
6	Heat recovery efficiency	x	
7	Overall energy efficiency	x	
8	Response of power output	x	
9	Start-up/shutdown characteristics	x	
10	Purge gas consumption	x	
11	Water consumption	x	
12	Waste heat	x	
	Environmental aspects		
1	Particulate emission	x	
2	SOx, NOx emission	x	
3	CO_2, CO emission	x	
4	Total hydrocarbon, hydrogen emission	x	
5	Audible noise level	x	
6	Vibration level	x	
7	Discharge water quality	x	

6 Test preparation

6.1 General

This Clause 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 part of IEC 62282 as the basis. A written test plan shall be prepared. Relevant test items are listed in Table 3.

The following items shall be considered for the test plan:

a) objective;
b) test specifications;
c) test personnel qualifications;
d) quality assurance standards (ISO 9000 or other equivalent standards);
e) target uncertainty (refer to Clauses A.1 and A.2);
f) identification of measurement instruments (refer to Clause 7);
g) estimated range of test parameters;
h) data acquisition plan (refer to 6.2.2);
i) where applicable, refer to basic safety considerations for the use of hydrogen as a fuel, (as indicated in the documentation provided by the end-product manufacturer).

6.2 Uncertainty analysis

6.2.1 Uncertainty analysis items

An uncertainty analysis shall be performed on the four test items below to indicate the reliability of the test results and to comply with customer requests. The following test results 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 power output;
– electrical efficiency;
– heat recovery efficiency;
– overall energy efficiency.

6.2.2 Data acquisition plan

The data acquisition system (i.e., the duration and frequency of readings) in order to meet the target uncertainty and the data recording equipment that is suitable for the required frequency of the readings and reading speed shall be prepared before the performance test (see 8.2 and Clause A.2).

7 Instruments and measurement methods

7.1 General

This Clause describes the measuring instruments used for testing the fuel cell power system, their method of usage and precautions to be taken. The types of instruments for measuring and measurement methods shall conform with the relevant International Standards and shall be selected to meet the measurement uncertainty targets specified by the manufacturer. If necessary, external equipment with required values shall be added.

The instruments and equipment given in 7.2 are typically used to measure the performance of fuel cell power systems.

7.2 Instruments

a) Instruments for measuring the electrical power output and power input:
   - voltmeter, ammeter, power meters, and other accessories.

b) Apparatus for measuring fuel consumption:
   - fuel flow meters, pressure sensors, temperature sensors.

c) Apparatus for determining the heating value of the fuel:
   - gas chromatography or alternate means with comparable accuracy;
   - calorimeter or alternate means with comparable accuracy.

d) Instruments for measuring the recovered heat:
   - fluid flow meters, temperature sensors, and pressure sensors.

e) Apparatus for determining the composition of exhaust gas and discharge water quality:
   - exhaust gas analyser; for example, particulate, SOx, NOx, CO_2, CO and total hydrocarbon;
   - water quality analyser; for example, pH meter, electrochemical probe.

f) Instruments for measuring noise:
   - noise level meter, microphones.

g) Instruments for measuring vibration:
   - vibration level meters, accelerometers, pick-up sensors.

h) Instruments for measuring ambient conditions:
   - barometers, hygrometers and temperature sensors.

7.3 Measurement methods

7.3.1 Electrical power

Electrical power measurement shall include electrical power output from the fuel cell power system, and electrical power inputs to handle parasitic loads. The measurement items are as follows:

a) power;

b) voltage;

c) current;

d) power factor.

They shall be measured in accordance with IEC 60051, IEC 60359, IEC 62052-11, IEC 62053-22, IEC 60688, IEC 61028, and IEC 61143.

1) Preparation for measurement

   Electrical power meters, voltage meters, current meters and power factor meters shall be appropriate in terms of accuracy and calibration before starting measurement.

2) Location of electrical power meters

   In order to measure electrical power output, an electrical power meter, voltage meter, current meter and power factor meter shall be located at the electric output interface point.

   In order to measure electrical power input for parasitic loads from an external power source, an electrical power meter, voltage meter, current meter and power factor meter shall be located at the electric input interface point.

   Power factor measurements shall be conducted with the fuel cell power system connected to an external load or connected to the local electrical power grid.

7.3.2 Fuel consumption

7.3.2.1 General

Either gaseous or liquid fuels may be used depending on the specifications of fuel cell power systems tested. Fuel heating values shall be consistent throughout the test period (see Table 4).

7.3.2.2 Gaseous fuel

Gaseous fuel characteristics shall include the determination of

a) heating value;
b) temperature;
c) pressure;
d) density.

Heating value gaseous fuel shall be calculated in accordance with 8.3.3.1.

7.3.2.3 Fuel composition

a) Sampling

   Fuel gas shall be sampled during operation of the fuel cell power system at a frequency and with an appropriate number of samples to meet the requirements of the uncertainty analysis.

   Pre-analysed bottled gas may be substituted for gas sampling, provided that the uncertainty of the analysed gas is consistent with the uncertainty required.

b) Fuel gas composition measurement

   Natural gas mainly comprises methane and small quantities of higher hydrocarbons, as well as some non-combustible gases. Other gaseous fuels may contain other constituents.

   All major components shall be measured according to methods detailed in ISO 6974 and ISO 6975:

   – methane;
   – ethane;
   – propane;

- butane;
- pentane;
- hexane plus;
- nitrogen;
- carbon dioxide;
- benzene.

The following minor components shall be measured according to methods detailed in ISO 6974 and ISO 6975:

- hydrogen;
- oxygen;
- carbon monoxide.

The sulphur compounds (including odorant) shall be measured according to methods detailed in ISO 6326.

The water vapour content shall be measured according to methods detailed in ISO 10101 and ISO 11541.

When hydrogen is used as a fuel, sampling and the determination of the gas composition shall be performed in accordance with ISO 14687.

7.3.2.4 Fuel flow

Fuel flow is essential to the measurement of fuel cell power system efficiency. Gas fuel consumption may be determined by means of either a volumetric meter, a mass flow meter, or a turbine-type flow meter. If such a method is not practicable, flow measurement by nozzles, orifices, or venturi meters is recommended, and they shall be applied in accordance with ISO 5167. Fuel flow meters shall be compatible with the pressure of gas used and their uncertainty shall be consistent with the uncertainty required.

Precautions for location of the flow meter and flow measurement are the following:

a) location of flow meters: flow meters shall be located near the test boundary;
b) measurement conditions: temperature and pressure of fuel shall be measured near the flow meter installed at the test boundary.

7.3.2.5 Fuel temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer;
b) resistance thermometer with transducer.

Temperature sensors shall be appropriate in terms of accuracy before starting measurement.

Temperature sensors shall be located just upstream of the flow measurement device.

7.3.2.6 Fuel pressure

Calibrated manometers, dead-weight gauges, Bourdon tubes or other elastic type gauges may be used. Alternatives include calibrated pressure transducers. Fuel pressure instrumentation shall be suitable for the pressures during the test and uncertainty shall be consistent with the uncertainty analysis.

Connecting piping shall be checked to be leak-free under working conditions before the performance test.

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

Fuel pressure measured shall be static pressure and effects of velocity shall be considered and eliminated.

7.3.3 Liquid fuel measurements

7.3.3.1 General

An appropriate sampling method shall be used to determine the fuel characteristics. This includes:

a) density (mass per unit volume);

b) heating value;

c) viscosity where applicable;

d) temperature;

e) liquid fuel composition.

These characteristics shall be determined in accordance with the relevant ISO standards (i.e. ISO 3648 and ISO 8217) as well as ASTM D4809–00 or by using a laboratory familiar with these International Standard methods.

7.3.3.2 Liquid fuel flow

The accurate measurement of fuel flow to the fuel cell power system is essential to determine a heat rate of the fuel cell power system. The use of flow nozzles, orifices, and venturi meters is recommended. Instrumentation shall be applied in accordance with ISO 5167. Alternatives include displacement meters, mass flow meters, volumetric meters, turbine type flow meters, calibrated liquid meters and direct weighing means. In any case, the uncertainty of fuel flow measuring devices used shall be known and shall be consistent with the uncertainty calculation.

No fuel spill or leakage after the point of measurement shall be allowed.

7.3.3.3 Liquid fuel temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer;

b) resistance thermometer with transducer.

Temperature sensors shall be appropriate in terms of accuracy before starting measurement, and shall be located just upstream of the fuel flow meter.

7.3.4 Recovered heat

7.3.4.1 General

Thermal media may be hot water, hot air or coolant such as oil, etc. A combination of these media may be used depending on the specifications of fuel cell power systems tested.

The temperature and pressure of heat transfer fluids shall be measured concurrently.

7.3.4.2 Fluid flow

Appropriate equipment for each thermal media shall be applied. The accurate measurement of thermal media flow to and from the thermal energy utilization/storage is necessary to determine the thermal efficiency of the fuel cell power system. The use of flow nozzles, orifices, or venturi meters is recommended, and they shall be applied in accordance with ISO 5167. Mass flow meters and turbine-type flow meters may also be used.

Flow meters shall be appropriate in terms of scale and accuracy before starting measurement.

Flow measuring devices shall be located near the boundary of the fuel cell power system.

7.3.4.3 Fluid temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer;
b) resistance thermometer with transducer;
c) appropriate fluid temperature measurement devices in terms of scale and accuracy before starting measurement;
d) fluid temperature measuring devices located near the boundary of the fuel cell power system.
e) temperature measurement devices located just upstream of the associated flow meter. Temperature sensors should not touch the pipe.

7.3.4.4 Fluid pressure

This measurement method is for gas phase fluid including steam.

a) Preparation for measurement: pressure gages shall be appropriate in terms of accuracy before starting measurement.
b) Location of pressure gages: pressure gage sensors shall be located just upstream of the associated flow meter near the interface points (fluid output and input points) in a fluid flow line. Adequate thermal insulation around pipes shall be required.
c) Appropriate compensation for condensation shall be applied.

7.3.5 Purge gas flow

Purge gas consumption shall be determined by means indicated in 7.3.7.

7.3.6 Oxidant (air) characteristics

7.3.6.1 General

Oxidant characteristics shall include the determination of:

a) temperature;
b) pressure;
c) composition (oxidant characteristics can affect fuel cell performance). The composition of the oxidant shall be stated in the test report;
d) density.

7.3.6.2 Oxidant (air) flow

Oxidant (air) flow rate may be determined by means of either a volumetric meter, a mass flow meter, or a turbine-type flow meter. If such a method is not practicable, flow measurement by nozzles, orifices, or venturi meters is recommended, and they shall be applied in accordance with ISO 5167. Flow meters shall be compatible with the pressure of gas used and uncertainty shall be consistent with the uncertainty analysis.

Precautions for location of the flow meter and measurement are the following:

a) location of flow meters;
b) flow meters shall be located near the test boundary.

7.3.6.3 Oxidant (air) temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer;
b) resistance thermometer with transducer.

Temperature sensors shall be appropriate in terms of accuracy before starting measurement.

Temperature sensors shall be located just upstream of the flow measurement device.

7.3.6.4 Oxidant (air) pressure

Calibrated manometers, dead-weight gages, Bourdon tubes or other elastic type gauges may be used. Alternatives include calibrated pressure transducers. Oxidant (air) pressure instrumentation shall be suitable for the pressures during the test and uncertainty shall be consistent with the uncertainty analysis.

Connecting piping shall be checked to be leak-free under working conditions in advance of the performance test.

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

Oxidant (air) pressure measured shall be static pressure and effects of velocity shall be considered and eliminated.

7.3.6.5 Oxidant (air) composition

Oxidant composition shall be measured using gas chromatography or other suitable means. If air is used as the oxidant, composition shall be considered to be ordinary atmospheric air unless otherwise indicated.

7.3.7 Other fluid flow

If necessary, the measurement of coolant water and drain water flows shall be accomplished by one of the following methods:

a) standard nozzle or orifice;

b) displacement meter;

c) other specified methods such as direct weighing or volumetric tanks, mass flow meters, etc.

7.3.8 Exhaust gas emission measurement

7.3.8.1 Exhaust gas temperature

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer;

b) resistance thermometer with transducer.

Exhaust gas temperature is used to quantify emissions and to correct the emissions rate for temperature.

Exhaust gas temperature instrumentation shall be installed just upstream of the exhaust gas flow meter and just upstream of the exhaust gas analyser.

7.3.8.2 Exhaust gas pressure

Calibrated manometers, dead-weight gauges, or other elastic type gauges may be used. Alternatives include calibrated pressure transducers. Exhaust gas pressure instrumentation shall be suitable for the pressures and temperatures during the test and instrumentation uncertainty shall be consistent with the uncertainty analysis.

Connecting piping shall be checked to be leak-free under working conditions before the performance test.

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

Exhaust gas pressure is used to quantify emissions and to correct emissions rate for pressure.

Exhaust gas pressure instrumentation shall be installed just upstream of the exhaust gas flow meter and just upstream of the exhaust gas composition analyser.

7.3.8.3 Exhaust gas flow

Refer to ISO 10780.

If ISO 10780 is not applicable, measurement of exhaust gas flow may be accomplished by mass flow meter, volumetric meter, or turbine-type flow meter. Flow measurement by nozzles, orifices, or venturi meters may be applicable. If nozzles, orifices, or venturi meters are used, they shall be applied in accordance with ISO 5167. Flow meters shall be compatible with the pressure of gas used and uncertainty shall be consistent with the uncertainty analysis.

7.3.8.4 Particulate concentration

Refer to ISO 9096, ISO 11042-1, and ISO 11042-2.

7.3.8.5 SOx and NOx concentration

SOx concentration:

Refer to ISO 7934, ISO 7935, ISO 11042-1, ISO 11042-2, and ISO 10396. Other methods suitable for the service may be used providing they are consistent with the uncertainty analysis.

NOx concentration:

Refer to ISO 11564, ISO 10849, ISO 11042-1, ISO 11042-2, and ISO 10396. Other methods suitable for the service may be used providing they are consistent with the uncertainty analysis.

7.3.8.6 CO_2 and CO concentration

CO_2: Refer to ISO 11042-1, ISO 11042-2, and ISO 10396.

CO_2 may be calculated on the basis of the carbon content of the fuel.

CO: Refer to ISO 11042-1, ISO 11042-2, and ISO 10396.

7.3.8.7 Total hydrocarbon concentration

Refer to ISO 11042-1 and ISO 11042-2.

7.3.8.8 Oxygen concentration

Refer to ISO 11042-1 and ISO 11042-2.

7.3.8.9 Hydrogen concentration

Utilise a catherometer or gas chromatograph or other suitable method to measure the hydrogen concentration in the exhaust gas stream(s).

7.3.9 Discharge water quality measurement

7.3.9.1 General

Discharge water quality measurements for water discharged from a fuel cell power system shall include the determination of

a) volume of discharge water;
b) temperature of discharged water;
c) pH(Hydrogen ion concentration);
d) Biochemical Oxygen Demand (BOD) or, if necessary, Chemical Oxygen Demand (COD);
e) emission levels of other substances which are restricted to the domestic law and might be emitted from fuel cell power system.

7.3.9.2 Volume of discharge water

Refer to 7.3.7.

7.3.9.3 Temperature of discharge water

Recommended instruments for measuring temperature directly are:

a) thermocouples with transducer;
b) resistance thermometer with transducer.

7.3.10 pH (Hydrogen ion concentration)

Refer to ISO 10523.

7.3.11 COD (Chemical Oxygen Demand)

Refer to ISO 6060.

7.3.12 BOD (Biochemical Oxygen Demand)

Refer to ISO 10707.

7.3.13 Audible noise level

Noise produced by the fuel cell power system shall be measured using a sound level meter as defined in IEC 61672-1 and IEC 61672-2. The test shall be conducted in accordance with ISO 3744.

The following parameters will be determined in accordance with ISO 3744:

a) measuring surface (at distance from the body of fuel cell power system);
b) number of measuring points;
c) influence of background noise.

The noise level will be measured at the locations and distances agreed to by the parties to the test.

7.3.14 Vibration level

Vibration shall be measured with the fuel cell power system installed and operated in accordance with the manufacturer's installation instructions.

Vibration emitted by the fuel cell power system shall be measured at the mounting points as described below.

Mounting hardware supplied by the manufacturer shall be used to mount the unit as required above. The mounting point is the transmission point, transmitting vibration from the unit to the ground, floor, walls, ceiling, or other support structure according to the manufacturer's design. If multiple mounting configurations are designed, all configurations shall be measured.

a) Measuring positions: measurements shall be taken at the mounting points that significantly respond to the dynamic forces and characterize the overall vibration of the system. For systems without fixed mounting points, dynamic analysis or preliminary testing is required to determine the significant measurement points.
b) To define the vibration behaviour at each measuring position, it is necessary to take measurements in three mutually perpendicular directions.
c) Mounting of accelerometers: refer to ISO 5348.

7.3.15 Total harmonic distortion

Total harmonic distortion shall be measured and reported for fuel cell power systems that produce alternating current. Refer to IEC 61000-4-7 and IEC 61000-4-13 for measurement guidance.

7.3.16 Ambient conditions

Ambient humidity, wind, pressure and temperature shall be measured.

Refer to ISO 4677-1 and ISO 4677-2 for ambient humidity measurement.

Refer to ISO 16622 for ambient wind measurement.

Recommended instruments for measuring ambient temperature directly are:

a) thermocouples with transducer;
b) resistance thermometer with transducer.

Temperature sensors shall be appropriate in terms of accuracy before starting measurement.

Recommended instruments for measuring ambient pressure directly are:

a) mercury barometer;
b) alcohol barometer.

Pressure sensors shall be appropriate in terms of accuracy before starting measurement.

8 Test method and computation of results

8.1 Test plan

8.1.1 General

The test items in Table 2 shall be carried out under different operating conditions depending upon the purpose of the test. The different conditions are

a) steady state at rated power;

b) steady state at partial load near the mid-point between rated power and minimum power level;
c) steady state at standby conditions at minimum power (0 %);
d) steady state where maximum values are found;
e) transient conditions.

Table 3 shows this information for all the test items.

8.1.2 Ambient conditions

For each test run, the following ambient conditions shall be measured:

a) ambient temperature;
b) barometric pressure;
c) relative humidity;
e) wind speed and direction.

Table 3 – Test item and system status

Item	Test	Steady state conditions			Maxi-mizing measured values	Transient state [b]
		Rated power	Partial load	Standby		
	Operation					
1	Electrical power output	X	X			
2	Total harmonic distortion	X	X			
3	Fuel consumption	X	X	X		
4	Oxidant consumption	X	X	X		
5	Electrical efficiency [a]	X	X			
6	Heat recovery efficiency [a]	X	X			
7	Overall energy efficiency	X	X			
8	Response of power output					X
9	Startup/shutdown characteristics					X
10	Purge gas consumption					X
11	Water consumption	X	X	X	X	
12	Waste heat	X	X	X		
	Environmental aspects					
1	Particulate emission				X	
2	SOx, NOx emission				X	
3	CO_2, CO emission				X	
4	Total hydrocarbon, hydrogen emission				X	
5	Audible noise level	X	X	X	X	X
6	Vibration level	X	X	X	X	X
7	Discharge water quality	X	X	X		

a Tests to be performed concurrently.

b Transient testing includes shutdown testing.

8.1.3 Maximum permissible variation in steady-state operating conditions

The maximum permissible variations are given in Table 4.

Variations beyond the allowable values in Table 4 are allowed, if the total uncertainty calculation results are acceptable to the parties to the test.

Table 4 – Maximum permissible variations in test operating conditions

Parameter	Allowable variation during a test run
System stabilization parameter as specified by the manufacturer and agreed to by all parties	As specified
Active power output, kW	±2 %
Total power, kVA	±2 %
Barometric pressure at site	±0,5 %
Inlet air temperature	±3 K
Heat value – fuel per unit volume	±1 %
Gaseous fuel pressure as delivered to system	±1 %
Absolute exhaust pressure	±0,5 %
Absolute inlet air pressure to system	±0,5 %
Heat rejection rate to external cooling rate	±2 %
Fuel flow	±2 %
Fuel temperature	±2 K
Secondary thermal energy input temperature	±3 K
Secondary thermal energy input delivery rate	±2 %
Inlet air/oxidant flow rate	Not specified
Thermal energy output delivery rate	±2 %
Total harmonic distortion THD[a]	±2 %

This table refers to ASME-PTC50. Instruments and measurement methods.

[a] For THD only: for the THD with a mean value of 5 %, its values between 3 % and 7 % are acceptable.

8.1.4 Test operating procedure

The following tests shall be done concurrently:

– electrical output power and recovered heat;
– fuel consumption and oxidant consumption;

NOTE Overall energy efficiency and waste heat in Table 3 are calculated on the basis of measured values given in the tests mentioned above.

The following other tests shall be executed efficiently during testing the test items mentioned above:

– water consumption, dynamic response of power output, start-up/shutdown and purge gas consumption.

8.2 Duration of test and frequency of readings

The appropriate duration and frequency of readings are determined according to the type of fuel cell power system tested. A sufficient number of measurements and number of measurement sets shall be established on the basis of requirements for data fluctuations, stability of average values, and the uncertainty analysis.

The evaluation of electrical power output, electrical efficiency and heat recovery efficiency (if applicable) shall be carried out three times consecutively, the duration of each test run being not less than 10 min. These conditions shall be determined by the results of the uncertainty analysis.

NOTE Whilst computing the results of the tests, the determination may be made with averaged values of observations made during a single test run.

8.3 Computation of results

8.3.1 Electrical power

Electrical power output and input shall be measured during a single test run in accordance with 7.3.1 at three different loads as defined in 8.1.

a) Electrical power output

When the voltage, current, and power factor of electrical power output are measured, electrical power output, P_{out} (W) is calculated as follows:

1) Three-phase system

$$P_{out} = \sqrt{3} \times V_{out} \times I_{out} \times \lambda_{out}$$

where

V_{out} is the voltage of electrical power output (line to line) (V);

I_{out} is the current of electrical power output (A);

λ_{out} is the power factor of electrical power output.

2) Single-phase system

$$P_{out} = V_{out} \times I_{out} \times \lambda_{out}$$

where

V_{out} is the voltage of electrical power output (line to neutral) (V);

I_{out} is the current of electrical power output (A);

λ_{out} is the power factor of electrical power output.

3) Direct current

$$P_{out} = V_{out} \times I_{out}$$

where

V_{out} is the voltage of electrical power output (V);

I_{out} is the current of electrical power output (A).

b) Electrical power input from external power source

The power input shall be measured as the same time as the power output is measured at each load.

When the voltage, current, and power factor of the electrical power input are measured, and expressed respectively as V_{in}, I_{in}, and λ_{in}, electrical power input, P_{in}, is calculated using the same equations as above.

8.3.2 Fuel consumption

8.3.2.1 General

This Clause provides the computation method to obtain the fuel consumption and fuel energy corresponding to the fuel consumption.

Fuel consumption shall be measured during the electrical power input and output testing in 8.3.1. Fuel consumption is measured in accordance with 7.3.2 and calculated by means of the following equations.

8.3.2.2 Gaseous fuel

$$q_{vf0} = q_{vf} \times (t_0/t_f) \times (p_f/p_0)$$

$$q_{mf} = q_{vf0} \times \rho_{f0}$$

where

q_{vf0} is the volumetric flow rate of fuel at the reference conditions (m^3/s);

q_{vf} is the volumetric flow rate of the fuel at temperature t_f and pressure p_f (m^3/s);

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

ρ_{f0} is the density of raw fuel at the reference conditions (kg/m^3);

t_0 is the reference temperature (288,15 K);

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

t_f is the temperature of fuel at test conditions (K);

p_f is the pressure of the fuel at test conditions (kPa).

8.3.2.3 Liquid fuel

$$q_{mf} = q_{vf0} \times \rho_{f0}$$

where

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

q_{vf0} is the volumetric flow rate of the fuel at the reference condition (m^3/s);

ρ_{f0} is the density of raw fuel at the reference conditions (kg/m^3).

8.3.3 Calculation of fuel energy

8.3.3.1 Gaseous fuel

The input energy of fuel at a temperature t_f, a pressure p_f of a mixture of known composition is calculated from the following equation

$$E_{fv} = (Q_{f0} + h_f - h_{f0} + E_{pf})/M_o$$

where

E_{fv} is the input energy of the fuel per unit of volume (kJ/m^3), as given in Table B.1 and Worksheet of Annex B;

Q_{f0} is the heating value of the fuel at reference conditions (kJ/mol);

h_f is the specific enthalpy of the fuel at temperature t_f (kJ/mol);

h_{f0} is the specific enthalpy of the fuel at the reference temperature t_0 (kJ/mol);

E_{pf} is the pressure energy of the fuel (kJ/mol);

M_o is the reference molar volume of ideal gas; ($2,3645 \times 10^{-2} m^3$/mol) (at the reference temperature for this standard, t_0 = 288,15 K).

The heating value of fuel, Q_{f0}, (kJ/mol), at the reference conditions is calculated as follows

$$Q_{f0} = \sum_{j=1}^{N} x_j \; Q_{f0\,j}$$

where

Q_{f0j} is the heating value of component j at the reference temperature t_0 (kJ/mol);

x_j is the molar ratio of component j, as given in Table B.1 and Worksheet of Annex B;

j is a component of the fuel;

N is the number of fuel gas constituent.

NOTE 1 Numerical values of Q_{f0j} are given in Table B.1.

The specific enthalpy of fuel, h_f (kJ/mol),is calculated from the equation

$$h_f = \sum_{j=1}^{N} x_j \; h_{fj}$$

where

h_{fj} is the specific enthalpy of component j at temperature t_f (kJ/mol);

x_j is the molar ratio of component j;

and, h_{fj} (kJ/mol) is given by the following equation

$$h_{fj} = (A_j \times t_f + (B_j/2\ 000) \times t_f^2 + (C_j/3 \times 10^6) \times t_f^3) \times 10^{-3}$$

where

A_j, B_j and C_j are the constants of component j and given in Worksheet 1 of Annex B;

t_f is the temperature of fuel at test conditions (K).

NOTE 2 The specific enthalpy of the fuel, h_{f0} (kJ/mol) at the reference temperature is calculated with substituting t_0 for t_f in the above equation of h_{fj}.

The pressure energy of fuel, E_{pf} (kJ/mol) is calculated from the following equation:

$$E_{pf} = R \times t_0 \times \ln(p_f / p_0)$$

where

R is the universal gas constant (8,314 J/mol K);

t_0 is the reference temperature (288,15 K);

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

p_f is the pressure of fuel (kPa).

8.3.3.2 Liquid fuel

The energy of fuel, E_{fv} (kJ/mol) at a temperature t_f is calculated from the following equation:

$$E_{fv} = \rho_f \times Q_{fl}$$

where

ρ_f is the density of fuel at temperature t_f (kg/m^3) and is measured according to the relevant International Standard applicable to liquid fuel applied to testing;

Q_{fl} is the measured heating value of the fuel (kJ/kg), and is measured according to the methods detailed in ASTM D4809–00 at temperature t_f.

8.3.4 Oxidant (air) consumption

Oxidant (air) flow is measured in accordance with 7.3.6 during testing as shown in Table 4.

When the measured flow rate of the oxidant (air) is provided in volume, the mass flow rate shall be calculated by means of the following equation:

$$q_{va0} = q_{va} \times (t_0/t_a) \times (p_a/p_0)$$

$$q_{ma} = q_{va0} \times \rho_{ao}$$

where

q_{va0} is the volumetric flow rate of the oxidant (air) at the reference conditions (m^3/s);

q_{va} is the volumetric flow rate of the oxidant (air) at temperature t_a and pressure p_a (m^3/s);

q_{ma} is the mass flow rate of the oxidant (air) (kg/s);

ρ_{ao} is the density of the oxidant (air) at the reference conditions (kg/m^3);

t_0 is the reference temperature (288,15 K);

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

t_a is the temperature of the oxidant at test conditions (K);

p_a is the pressure of the oxidant at test conditions (kPa).

NOTE These values are provided as average values during the test period.

8.3.5 Calculation of oxidant (air) energy

When hot or pressurized oxidant (air) is directly supplied to the fuel cell power system, the energy of the oxidant (air) shall be calculated on the basis of the conditions of the oxidant (air) at the interface point of the fuel cell power system.

The energy of air at a temperature t_a and a pressure p_a is calculated from the equation:

$$E_{av} = (h_a - h_{a0} + E_{pa})/M_0$$

where

E_{av} is the input energy of the oxidant (air) per unit of volume (kJ/m^3);

h_a is the specific enthalpy of the oxidant (air) at temperature t_a (kJ/mol);

h_{a0} is the specific enthalpy of the oxidant (air) at reference temperature t_0 (kJ/mol);

E_{pa} is the pressure energy of the oxidant (air) (kJ/mol);

M_o is the reference molar volume of ideal gas ($2,3645 \times 10^{-2}$ m^3/mol) (at the reference temperature, t_0 = 288,15 K).

The specific enthalpy of air at the temperature t_f is calculated from the equation:

$$h_a = (A_a \times t_a + (B_a/2\,000) \times t_a^2 + (C_a/3 \times 10^6) \times t_a^3) \times 10^{-3}$$

where

h_a is calculated. Other oxidants shall have the enthalpy calculated separately (kJ/mol);

A_a, B_a, and C_a are the constants of oxidant (air), and the numerical values of A_a, B_a, and C_a, (for air) are given in Worksheet 2 of Annex B;

t_a is the temperature of oxidant (K).

The pressure energy of oxidant (air), E_{pa} (kJ/mol) is calculated by the equation:

$$E_{pa} = R \times t_0 \times \ln(p_a/p_0)$$

where

R is the universal gas constant (8,314 J/mol K);

t_0 is the reference temperature (288,15 K);

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

p_a is the pressure of oxidant (kPa).

8.3.6 Electrical efficiency

Electrical efficiency is calculated as follows, based on the measurement values of the electrical power output and input given in 8.3.1 and input energy supplied by the fuel and the oxidant (air) respectively given in 8.3.3 and 8.3.5.

NOTE If HHV, higher heating value is applied for Q_{in}, see 4.3.

The electrical efficiency η_e (%);

$$\eta_e = \frac{(P_{out} - P_{in})}{Q_{in}} \times 100$$

And the input energy supplied by fuel and oxidant, Q_{in}, (kJ/s):

$$Q_{in} = (q_{vf0} \times E_{fv} + q_{va0} \times E_{av})$$

such that

$$\eta_e = \frac{(P_{out} - P_{in})}{(q_{vf0} \times E_{fv} + q_{va0} \times E_{av})} \times 100$$

where

P_{out} is the active power of electrical power output (kW);

P_{in} is the active power of electrical power input for parasitic load, etc.(kW);

E_{fv} is the input energy of the fuel per unit volume (kJ/m^3);

E_{av} is the input energy of the air per unit volume (kJ/m^3);

q_{vf0} is the volumetric flow rate of the fuel at the reference conditions, t_0 and p_0 (m^3/s);

q_{va0} is the volumetric flow rate of the air at the reference conditions, t_0 and p_0 (m^3/s).

8.3.7 Heat recovery efficiency

8.3.7.1 General

The recovered heat shall be measured in accordance with 7.3.4, during the electrical power input and electrical power output performance tests in 7.3.1. The recovered heat is calculated by the equation given in 8.3.7.2.

Heat recovery efficiency is calculated by the equation in 8.3.7.3 on the basis of the measurement values of the recovered heat given in 7.3.4 and the input energy Q_{in}, (kJ/s) in 8.3.6.

NOTE If HHV, higher heating value is applied for Q_{in}, see 4.3.

8.3.7.2 Calculation of heat recovery rate

The recovered thermal power, $Q_{HR,}$ is calculated by means of the following equation:

$$Q_{HR} = h_{HR1} \times q_{mHR1} - h_{HR2} \times q_{mHR2}$$

where

h_{HR1} is the specific enthalpy (kJ/kg) of heat recovery fluid at temperature t_{HR1} and at pressure p_{HR1};

h_{HR2} is the specific enthalpy (kJ/kg) of heat recovery fluid at temperature t_{HR2} and at pressure p_{HR2};

q_{mHR1} is the mass flow rate of heat recovery fluid at the interface of fluid output (kg/s);

q_{mHR2} is the mass flow rate of heat recovery fluid at the interface of fluid input (kg/s).

8.3.7.3 Heat recovery efficiency calculation

Heat recovery efficiency is calculated in per cent.

The heat recovery efficiency η_{th} (%);

$$\eta_{th} = \frac{Q_{HR}}{Q_{in}} \times 100$$

such that,

$$\eta_{th} = \frac{Q_{HR}}{(q_{vf0} \times E_{fv} + q_{va0} \times E_{av})} \times 100$$

where

Q_{HR} is the recovered thermal power (kJ/s);

Q_{in} is the input power supplied by fuel and oxidant (kJ/s);

Q_{in} is shown in 8.3.6.

8.3.8 Overall energy efficiency

The overall energy efficiency, η_{total} (%) is calculated as follows,

$$\eta_{total} = \eta_e + \eta_{th}$$

where

η_e is the electrical efficiency (%);

η_{th} is the heat recovery efficiency (%).

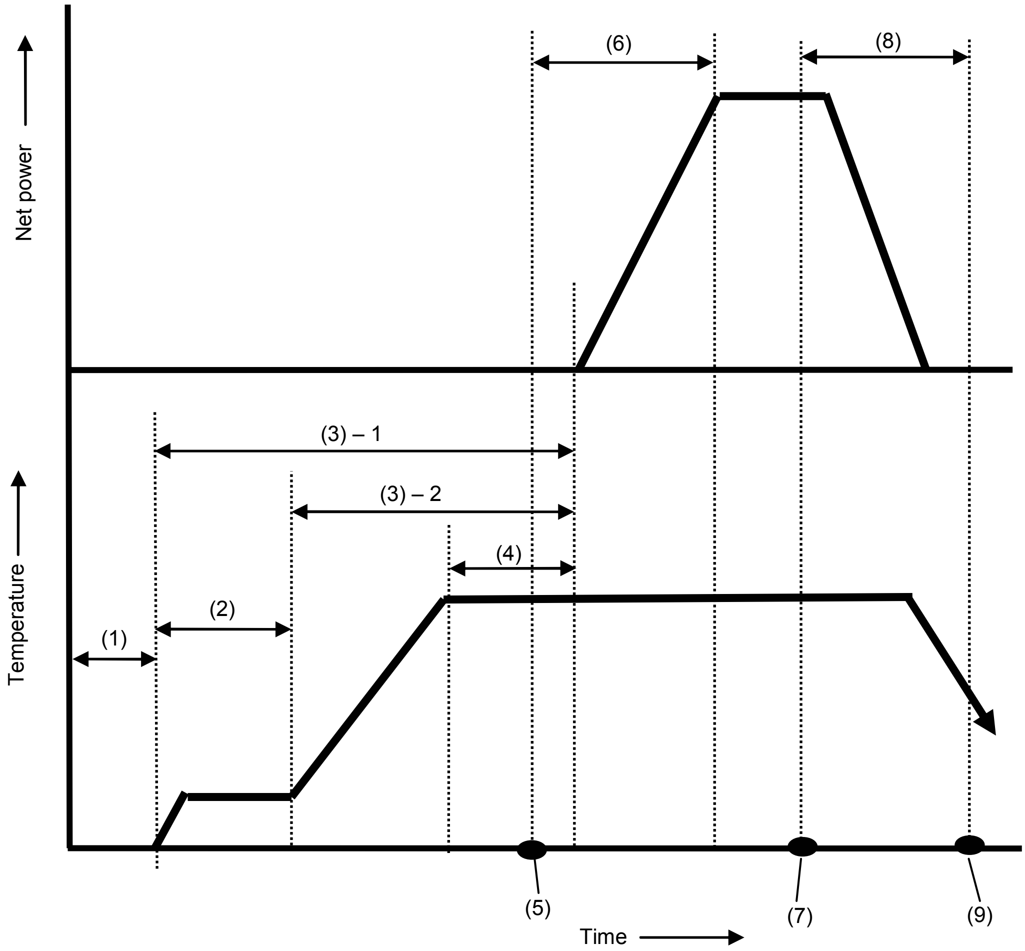
8.3.9 Power and thermal response characteristics

8.3.9.1 General

Figure 3 provides more information for the definitions from 3.1.10 to 3.1.14.

Figure 4 provides more information for the tests in 8.3.9.2.2, 8.3.9.3.2 and 8.3.9.4.2.

Figure 5 provides more information for the tests in 8.3.9.2.3, 8.3.9.3.3 and 8.3.9.4.3.



Key

(1) Cold state (shutdown) ambient temperature, zero power input

(2) Storage state

Start-up time

(3)-1 For systems that do not require external power to maintain a storage state, this is measured from the cold state

(3)-2 For systems that require external power to maintain a storage state, this is measured from the storage state

(4) Standby state

(5) Power up action initiated

(6) Response time to rated power

(7) Shutdown action initiated

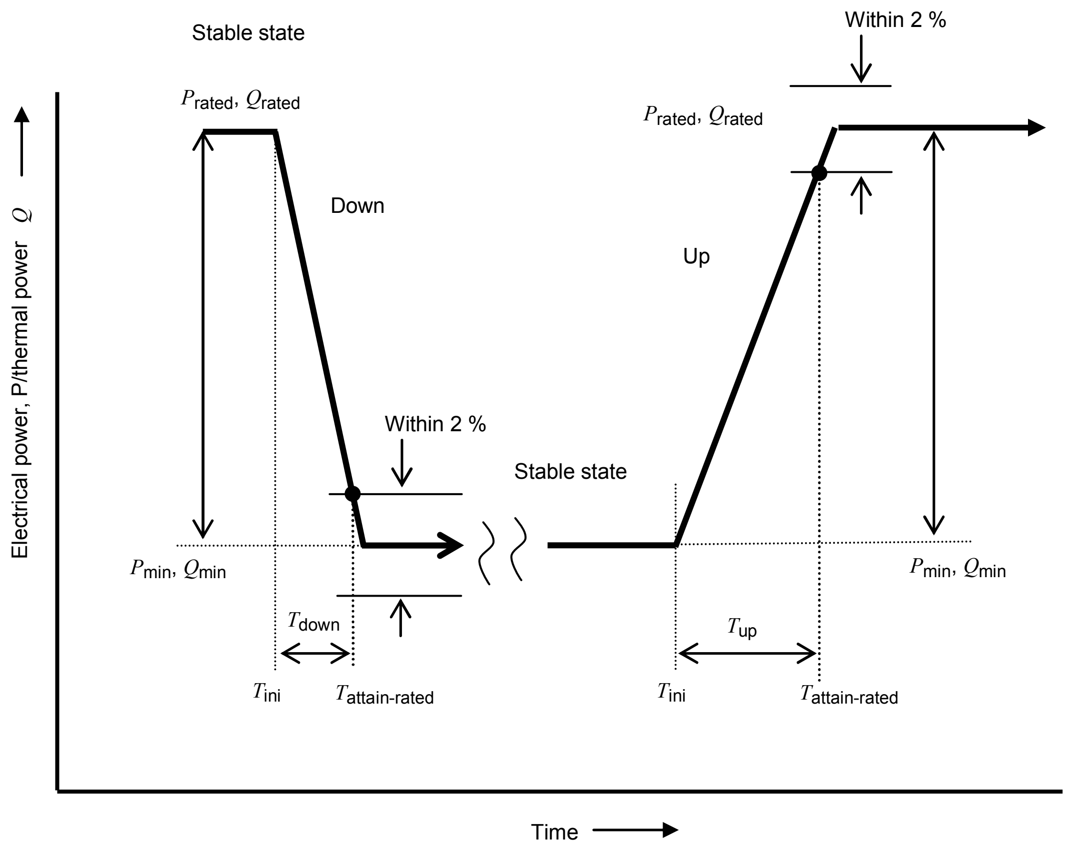
(8) Shutdown time

(9) Shutdown condition specified

Operational mode

The process from **(2) to (8)**

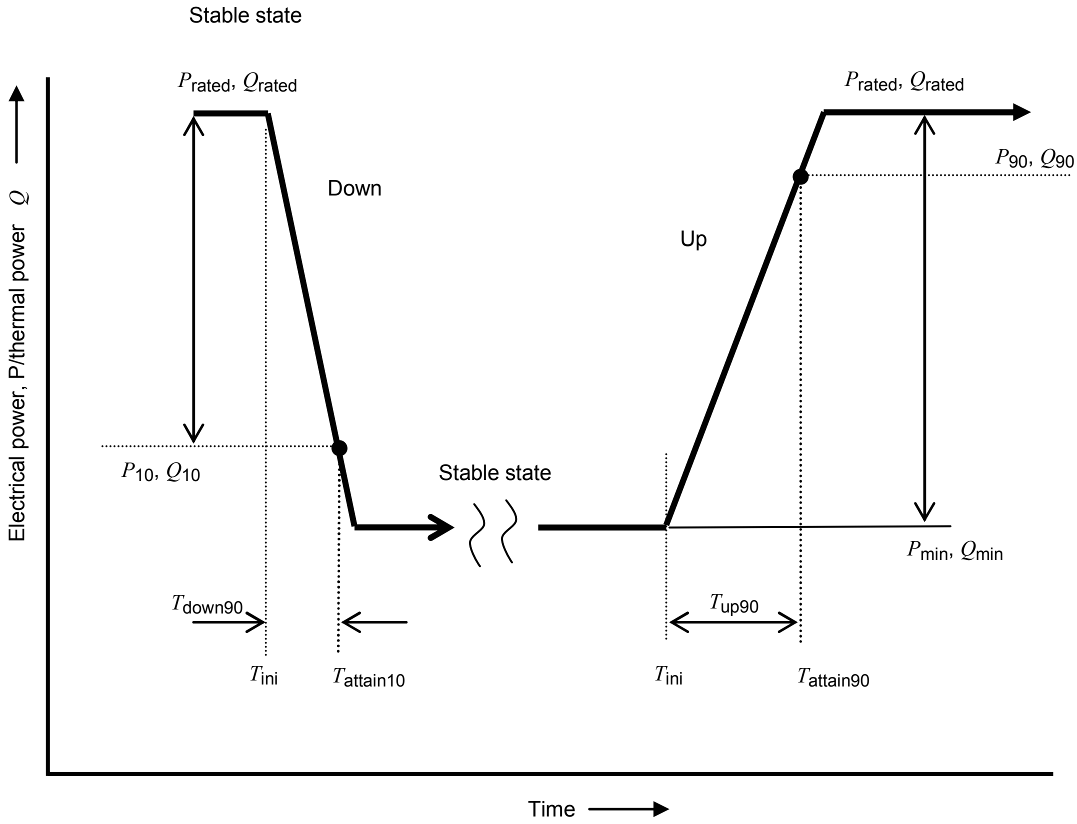
Figure 3 – Operating process chart of fuel cell power system



Key

P_{rated}, Q_{rated}	Nominal electrical power, thermal power output respectively
P_{mini}, Q_{mini}	Minimum power output, thermal power output respectively
T_{ini}	Time at starting the power output change
$T_{attain-rated}$	Time to attain within 2 % of rated power output
$T_{attain-mini}$	Time to attain within 2 % of minimum power output
T_{down}	Period from T_{ini} to T_{attain}
T_{up}	Period from T_{ini} to T_{attain}

Figure 4 – Power response time ramp rates



Key

P_{rated}, Q_{rated}	Nominal power output, thermal rated power output respectively
P_{min} ,$Q_{min.}$	Minimum power output, minimum thermal power output respectively
P_{10}, Q_{10}	P_{10} electrical power output at a low net power level corresponding to 90 % of the total downward difference between rated power and minimum power (W, kW). This may be more than 10 % of rated power and shall be calculated on the basis of the rated power and the minimum power for each type of unit, in accordance with the manufacturer's specifications, as well as for Q_{10}, thermal power output (kJ/s/s, W, kW)
P_{90}, Q_{90}	Electrical power output at 90 % of rated electrical power output (W, kW), as well as for Q_{90}, thermal power output (kJ/s/s, W, kW)
T_{ini}	Time at start of the power output change
$T_{attain90}$	Time at attainment of P_{90}
$T_{attain10}$	Time at attainment of P_{10}
T_{down90}	Period from T_{ini} to $T_{attain10}$ (s)
T_{up90}	Period from T_{ini} to $T_{attain90}$ (s)

Figure 5 – 90 % response time ramp rates

8.3.9.2 Grid-independent systems power response times

8.3.9.2.1 Maximum acceptable instantaneous electrical power output transient for grid-independent systems

For fuel cell power systems designed for stand-alone operations (i.e., independent from the electrical grid), this test procedure is designed to determine the maximum electrical power transient that a fuel cell power system can accept without changing operating mode. The test shall be conducted feeding a resistive load.

The net electrical power output, measured in accordance with 7.3.1, is monitored continuously during this test.

An electrical power transient is deemed acceptable to the fuel cell power system if the change in net electrical power output between an initial steady-state value (see 8.1 and Table 4) and a new value of net electrical power output can occur within 20 ms [1]. Only net electrical power output is monitored; any instability or subsequent variation of other parameters listed in Table 4, as well as system stabilization parameters (as specified by the manufacturer) and total harmonic distortions, is disregarded in this test.

The manufacturer shall specify a target transient level. For example, a manufacturer may specify a target transient level (for example, 57 %) as their maximum transient capability. Testing is started at the target value. If the test is successful, an additional test may be performed at a higher power level as specified by the manufacturer to verify a higher capability. If the initial test fails, other testing shall be conducted using a smaller transient power level change, as specified by the manufacturer. At least one test shall be successful for a result to be reported.

An up-transient is obtained with an initial steady state of net electrical power output value equal to 0 % rated power output, with the system in the standby state.

A down-transient is obtained with an initial steady state of net electrical power value equal to 100 % rated power.

8.3.9.2.2 Grid-independent net electrical power output transient

For fuel cell power systems designed for grid-independent operation, the power response time defined in 3.1.15 for net electrical power output shall be observed between two steady-state operating conditions with respect to total harmonic current distortion [2] and total harmonic voltage distortion when the maximum acceptable instantaneous electrical power output transient defined in 8.3.9.2.1, is required from the fuel cell power system feeding a resistive load.

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1 That is, one period of a 50 Hz signal. This criterion is also applicable to fuel cell power systems that provide 60 Hz alternating current and to those that provide continuous current. For systems where this time limit is inappropriate by design, the manufacturer may specify a different time limit and take specific exception to this in the report.

2 Total harmonic current distortion is equal to the square root of the sum of squares of the amplitudes of harmonic currents or voltages (up to the 50^{th} harmonic) divided by the magnitude of the fundamental waveform.

The response duration of net electrical power output shall be calculated by means of the following equation:

$$T_{up} = T_{attain\text{-}rated} - T_{ini}$$

$$T_{down} = T_{attain\text{-}mini} - T_{ini}$$

where

T_{ini} is the time when the electrical load change signal is sent, in either direction;

$T_{attain\text{-}rated}$ is the time when the variation of total harmonic distortion values have reached the value of Table 4, thereby defining a new steady-state operating condition at the higher demand level;

$T_{attain\text{-}mini}$ is the time when the variation of total harmonic distortion values have reached the value of Table 4, thereby defining a new steady-state operating condition at the lower demand level.

a) Grid-independent down-transient to steady-state total harmonic distortion
   1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at rated electrical power output.
   2) The request signal for an electrical power-down with a step equal to that determined in 8.3.7.2 is sent to the controllers of the fuel cell power system.
   3) The fuel cell power system decreases in electrical power output according to this control signal.
   4) The response duration from initiation of the electrical power demand signal until the variation of the total harmonic distortion values have reached the value of Table 4, thereby defining a new steady-state operating condition with respect to total harmonic distortion, shall be observed and recorded.
b) Grid independent up-transient to steady-state total harmonic distortion
   1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at minimum electrical power output.
   2) The request signal for an electrical power-up with a step equal to that determined in 8.3.7.2 is sent to the controllers of the fuel cell power system.
   3) The fuel cell power system increases in electrical power output according to this control signal.
   4) The power response duration from initiation of the electrical power demand signal until the variation of the total harmonic distortion values have reached the value of Table 4, thereby defining a new steady-state operating condition with respect to total harmonic distortion, shall be observed and recorded.

8.3.9.2.3 Grid-independent 90 % power response time

For fuel cell power systems designed for grid-independent operation, the power response time defined in 3.1.15 for net electrical power output shall be observed between two operating conditions with respect to attaining 90 % of the demand signal when the maximum acceptable instantaneous electrical power output transient defined in 8.3.9.2.1, is required from the fuel cell power system feeding a resistive load.

The 90 % response time of net electrical power output shall be calculated by means of the following equation:

$$T_{\text{down90}} = T_{\text{attain-down90}} - T_{\text{ini}}$$

$$T_{\text{up90}} = T_{\text{attain-up90}} - T_{\text{ini}}$$

where

T_{ini} is the time when the electrical load change signal is sent, in either direction;

$T_{\text{attain-down90}}$ is the time when the net electrical power reaches 90 % of the lower demand value determined in 8.3.9.2.1, is reached;

$T_{\text{attain-up90}}$ is the time when the net electrical power reaches 90 % of the upper demand value determined in 8.3.9.2.1, is reached.

a) Grid-independent down-transient to 90 % of maximum instantaneous demand

   1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at rated electrical power output.
   2) The request signal for an electrical power-down with a step equal to that determined in 8.3.9.2.1, is sent to the controllers of the fuel cell power system.
   3 The fuel cell power system decreases in electrical power output according to this control signal.
   4) The response duration shall be observed and recorded from initiation of the electrical power-down demand signal until the net power output reaches 90 % of the demand.

b) Grid-independent up-transient to 90 % of maximum instantaneous demand

   1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at minimum electrical power output.
   2) The request signal for an electrical power-up with a step equal to that determined in 8.3.9.2.1, is sent to the controllers of the fuel cell power system.
   3) The fuel cell power system increases in electrical power output according to this control signal.
   4) The power response duration shall be observed and recorded from initiation of the electrical power-up demand signal until the net power output reaches 90 % of the demand step.

8.3.9.3 Grid-connected systems power response time

8.3.9.3.1 General

This subclause covers fuel cell power systems intended for grid-connected operation.

The power response time as defined in 3.1.15 will be measured during grid-connected operational power transients as defined below.

The electrical power output shall be measured continuously during the test in accordance with 7.3.1.

8.3.9.3.2 Grid-connected net electrical power output response to rated power

The ramp rate of the power response of electrical power output to and from rated power shall be calculated with reference to Figure 4 by means of the following equation:

a) Up-power response of electrical power output

$$PR_{\text{min}} = (P_{\text{rated}} - P_{\text{min}})/(T_{\text{attain-min}} - T_{\text{ini}}) = (P_{\text{rated}} - P_{\text{min}})/T_{\text{down}}$$

b) Down-power response of electrical power output

$$PR_{\text{rated}} = (P_{\text{rated}} - P_{\text{min}})/(T_{\text{attain-rated}} - T_{\text{ini}}) = (P_{\text{rated}} - P_{\text{min}})/T_{\text{up}}$$

where

PR_{min} is the ramp rate from rated to minimum power (W/s, kW/s);

PR_{rated} is the ramp rate from minimum to rated power (W/s, kW/s);

P_{min} is the electrical power output at minimum electrical power output (W, kW);

P_{rated} is the electrical power output at rated electrical power output (W, kW);

T_{ini} is the time at start of the load change, either direction;

$T_{\text{attain-min}}$ is the time at attainment of the minimum electrical power output within 2 %;

$T_{\text{attain-rated}}$ is the time at attainment of the rated electrical power output within 2 %;

T_{down} is the period from T_{ini} to $T_{\text{attain-min}}$ (s);

T_{up} is the period from T_{ini} to $T_{\text{attain-rated}}$ (s).

c) Down-power response of electrical power output

1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at rated electrical load.
2) The electrical power-down signal to minimum electrical load is sent to the controllers of the fuel cell power system.
3) The fuel cell power system decreases in electrical power output according to this control signal.
4) The power response duration from initiation of the electrical power demand signal until attaining minimum electrical power output, within ±2 %, shall be observed and reported.

d) Up-power response of electrical power output

1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at minimum electrical power output.
2) The electrical power-up signal to rated electrical load is sent to the controllers of the fuel cell power system.
3) The power system increases in electrical power output according to this control signal.
4) The power response duration from initiation of the electrical power demand signal until attaining rated electrical power output, within ±2 %, shall be observed and reported.

8.3.9.3.3 Grid-connected 90 % power response time

The response time to 90 % of demand as defined in 3.1.16 shall be measured. The electrical power output shall be measured continuously during the test in accordance with 7.3.1.

The ramp rate of the response of electrical power output shall be calculated with reference to Figure 5 by means of the following equation:

a) Down-power response of electrical power output

$$PR_{\text{down90}} = (P_{\text{rated}} - P_{10})/(T_{\text{attain10}} - T_{\text{ini}}) = (P_{\text{rated}} - P_{10})/T_{\text{down}}$$

b) Up-response of electrical power output

$$PR_{\text{up90}} = (P_{90} - P_{\text{min}})/(T_{\text{attain90}} - T_{\text{ini}}) = (P_{90} - P_{\text{min}})/T_{\text{up}}$$

where

PR_{up90} is the ramp rate from minimum electrical power to 90 % of rated electrical power (W/s, kW/s);

PR_{down90} is the ramp rate from rated electrical power to a power level corresponding to 90 % of the total downward difference between rated electrical power and minimum electrical power (W/s, kW/s);

P_{rated} is the electrical power output at rated electrical power output (W, kW);

P_{90} is the electrical power output at 90 % of rated electrical power output (W, kW);

P_{10} is the electrical power output at a low net power level corresponding to 90 % of the total downward difference between rated power and minimum power (W, kW). This may be more than 10 % of rated power and shall be calculated on the basis of the rated power and the minimum electrical power for each type of unit, in accordance with the manufacturer's specifications;

P_{min} is the electrical power output at minimum electrical power output (W, kW);

T_{ini} is the time when the electrical power output change starts, in either direction;

T_{attain90} is the time at attainment of P_{90};

T_{attain10} is the time at attainment of P_{10};

T_{down} is the period from T_{ini} to T_{attain10} (s);

T_{up} is the period from T_{ini} to T_{attain90} (s).

c) Down-response of electrical power output

1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at rated electrical power output.
2) The electrical power-down signal to minimum electrical power output is sent to the controllers of the fuel cell power system.
3) The fuel cell power system decreases in electrical power output according to this control signal.
4) The response duration from initiation of the electrical power output demand signal until attaining 90 % of the step change demand shall be observed and recorded.

d) Up-response of electrical power output

1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at minimum electrical power output.
2) The electrical power-up signal to rated electrical power output is sent to the controllers of the fuel cell power system.
3) The power system increases in electrical power output according to this control signal.
4) The power response duration from initiation of the electrical power output demand signal until attaining 90 % of rated electrical power output shall be observed and recorded.

8.3.9.4 Thermal power output response

8.3.9.4.1 General

This subclause covers fuel cell power systems intended to control primarily on thermal power output or which can operate in that mode.

The thermal power response duration as defined in 3.1.15 will be measured during operational thermal power transients as defined below. The electrical and thermal power outputs shall be measured continuously during the test in accordance with 7.3.1 and 7.3.4.

8.3.9.4.2 Rated thermal power output response

The ramp rate of the thermal power output to and from rated thermal power shall be calculated with reference to Figure 4 by means of the following equation:

a) Down-response of rated thermal power output

$$QR_{\mathrm{min}} = (Q_{\mathrm{rated}} - Q_{\mathrm{min}})/(T_{\mathrm{attain\text{-}min}} - T_{\mathrm{ini}}) = (Q_{\mathrm{rated}} - Q_{\mathrm{min}})/\, T_{\mathrm{down}}$$

b) Up-response of rated thermal power output

$$QR_{\mathrm{rated}} = (Q_{\mathrm{rated}} - Q_{\mathrm{min}})/(T_{\mathrm{attain\text{-}rated}} - T_{\mathrm{ini}}) = (Q_{\mathrm{rated}} - Q_{\mathrm{min}})/\, T_{\mathrm{up}}$$

where

QR_{rated} is the ramp rate (kJ/s/s, or W/s, kW/s) from minimum thermal power to rated thermal power;

QR_{min} is the ramp rate (kJ/s/s, or W/s, kW/s) from rated thermal power to minimum thermal power;

Q_{rated} is the thermal power output at rated thermal power output (recovered heat: Q_{HR}) (kJ/s, or W, kW);

Q_{min} is the thermal power output at minimum thermal power output (recovered heat: Q_{HR}) (kJ/s, W, kW);

T_{ini} is the time at the start of the thermal power output change, in either direction;

$T_{\mathrm{attain\text{-}rated}}$ is the time at attainment of steady-state rated thermal power output, within ±2 %.

$T_{\mathrm{attain\text{-}min}}$ is the time at attainment of steady-state minimum thermal power output, within ±2 %;

T_{down} is the period from T_{ini} to $T_{\mathrm{attain\text{-}min}}$ (s);

T_{up} is the period from T_{ini} to $T_{\mathrm{attain\text{-}rated}}$ (s).

c) Down-response of rated thermal power output

1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at rated thermal power output.

2) The thermal power-down signal to minimum thermal load is sent to the controllers of the fuel cell power system.

3) The fuel cell power system decreases in thermal power output according to this control signal.

4) The response duration from initiation of the thermal power-down demand signal until attaining minimum thermal power output, within ±2 %, shall be observed and reported.

d) Up-response of rated thermal power output

1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at minimum thermal power output.

2) The thermal power-up signal to rated thermal power output is sent to the controllers of the fuel cell power system.

3) The power system increases in thermal power output according to this control signal.

4) The response duration from initiation of the thermal power-up demand signal until attaining rated thermal power output, within ±2 %, shall be observed and reported.

8.3.9.4.3 90 % thermal power output response

The ramp rate of the thermal power output to 90 % of demand shall be calculated with reference to Figure 5 by means of the following equation:

a) Thermal power output down-response to 90 % of demand

$$QR_{\mathrm{down90}} = (Q_{\mathrm{rated}} - Q_{10})/(T_{\mathrm{attain\text{-}10}} - T_{\mathrm{ini}}) = (Q_{\mathrm{rated}} - Q_{10})/T_{\mathrm{down}}$$

b) Thermal power output up-response to 90 % of demand

$$QR_{\mathrm{up90}} = (Q_{90} - Q_{\mathrm{min}})/(T_{\mathrm{attain\text{-}90}} - T_{\mathrm{ini}}) = (Q_{90} - Q_{\mathrm{min}})/T_{\mathrm{up}}$$

where

QR_{down90} is the ramp rate from rated thermal power to a thermal power level corresponding to 90 % of the total downward difference between rated thermal power and minimum thermal power; (kJ/s/s, W/s, or kW/s);

QR_{up90} is the ramp rate from minimum thermal power to 90 % of rated thermal power (kJ/s/s, W/s, or kW/s);

Q_{rated} is the thermal power output at rated thermal power output (recovered heat: Q_{HR}) (kJ/s, or W, kW);

Q_{90} is the thermal power output at 90 % of rated thermal power output (W, kW);

Q_{10} is the thermal power output at a low thermal power level corresponding to 90 % of the total downward difference between rated thermal power and minimum thermal power (W, kW). This may be more than 10 % of rated thermal power and shall be calculated on the basis of the rated power and the minimum electrical power for each type of unit, in accordance with manufacturer's specifications.

Q_{min} is the thermal power output at minimum thermal power output (recovered heat: Q_{HR}) (kJ/s, W, kW);

T_{ini} is the time at the start of the thermal power output change, in either direction;

$T_{attain10}$ is the time at attainment of the thermal power output level corresponding to 90 % of the total downward difference between rated thermal power and minimum thermal power, within ±2 %;

$T_{attain90}$ is the time at attainment of the thermal power output of 90 % of rated thermal power output, within ±2 %;

T_{down} is the period from T_{ini} to $T_{attain10}$ (s);

T_{up} is the period from T_{ini} to $T_{attain90}$ (s).

c) Down-response of thermal power output
   1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at rated thermal power output.
   2) The thermal power-down signal to minimum thermal load is sent to the controllers of the fuel cell power system.
   3) The fuel cell power system decreases in thermal power output according to this control signal.
   4) The response duration from initiation of the thermal power-down demand signal until attaining minimum thermal power output, within ±2 %, shall be observed and reported.

d) Up-response of thermal power output
   1) The fuel cell power system shall be confirmed to be in a steady-state operating condition at minimum thermal power output.
   2) The thermal power-up signal to rated thermal power output is sent to the controllers of the fuel cell power system.
   3) The power system increases in thermal power output according to this control signal.
   4) The response duration from initiation of the thermal power-up demand signal until attaining rated thermal power output, within ±2 %, shall be observed and reported.

8.3.10 Start-up and shutdown characteristics

The test item includes the measurement of

a) start-up time (see 3.1.13);
b) shutdown time (see 3.1.14);
c) start-up energy (see 3.1.18).

The manufacturer shall specify the conditions for the storage state and the standby state, as defined in 3.1.11 and 3.1.12, respectively. See Figure 3 for additional information.

The test for a) and b) listed above consists of measuring the time between the initiation of the command for the start-up or shutdown until the requested status is attained.

For c) listed above, the energy during the start up shall be measured. Electrical power output and thermal power output shall be measured concurrently during the start-up energy test in accordance with 7.3.1 and 7.3.4, respectively.

8.3.11 Purge gas consumption

Measure purge gas flow rate according to 7.3.7.

a) Separately carry out the measurement of purge gas consumption at the following conditions:
   1) cold state;
   2) start-up;
   3) normal shutdown;
   4) emergency shutdown;
   5) storage state.
b) In the measurement of purge gas consumption during start-up, measure the amount of purge gas used from the instant when the start-up process is initiated to the instant when the start-up is completed.
c) In the measurement of purge gas consumption during a normal shutdown, measure the amount of purge gas used from the instant when the normal shutdown process is initiated to the instant when the shutdown is completed.
d) In the measurement of purge gas consumption during an emergency shutdown, measure the amount of purge gas used from the instant when the emergency shutdown process is initiated to the instant when the emergency shutdown is completed.
e) In the measurement of purge gas consumption during the storage state, measure the amount of purge gas used per hour after completion of normal shutdown or emergency shutdown process.

8.3.12 Water consumption

Water consumption, q_{vw} (m^3/s) shall be measured in accordance with 7.3.7 at the conditions specified in Table 3.

The power level shall be measured and recorded during the tests.

The duration of each test run shall be measured and recorded.

The net amount of water consumed during each test run shall be measured and recorded. Water consumed from or stored within the system shall also be measured and taken into account.

8.3.13 Waste heat

The waste heat is calculated by the equation:

$$Q_{\text{WH}} = q_{\text{vf0}} \times E_{\text{fv}} + q_{\text{va0}} \times E_{\text{av}} - (P_{\text{out}} - P_{\text{in}}) - Q_{\text{HR}}$$

where

Q_{WH} is the waste heat (kJ/s);

q_{vf0} is the volumetric flow rate of the fuel at reference conditions (m^3/s);

E_{fv} is the input energy of fuel per unit volume (kJ/m^3);

q_{va0} is the volumetric flow rate of the oxidant (air) at reference conditions (m^3/s);

E_{av} is the input energy of air per unit volume (kJ/m^3);

P_{out} is the active power of electrical power output (kW);

P_{in} is the active power of electrical power input from external power source (kW);

Q_{HR} is the energy of recovered heat (kJ/s).

8.3.14 Exhaust gas emission

This test procedure is confirmation of the emission characteristics emitted from a fuel cell power system operated under the following conditions:

a) measure the peak concentration of each constituent as described in 7.3.8 during a start-up;
b) measure the peak concentration of each constituent as described in 7.3.8 during a shutdown;
c) measure the amount of each constituent as described in 7.3.8 during operation at partial power output specified in 8.1 and Table 3;
d) measure the amount of each constituent as described in 7.3.8 during operation at rated power output.

Emission of particulate, SOx, NOx, CO_2, CO, total hydrocarbon and hydrogen shall be continuously measured according to 7.3.8, 8.1 and Table 3. The exhaust gas temperature, pressure, and flow rate shall be measured according to 7.3.8.1, 7.3.8.2 and 7.3.8.3, respectively.

8.3.15 Calculation of emission production

The quantity of a specified gas emission shall be calculated as follows:

$$q_{\mathrm{me}} = q_{\mathrm{ve}} \times \rho_{\mathrm{e}}$$

where

q_{me} is the mass flow rate of gas emission component (kg/s);

q_{ve} is the measured volumetric flow rate of exhaust gas (m^3/s);

ρ_{e} is the mass concentration of a specified gas component (kg/m^3).

These ρ_{e} values shall be corrected using ISO 7934 for actual temperature, actual pressure, and wet/dry conditions.

Exhaust gas oxygen concentration shall be measured and reported.

8.3.16 Audible noise level

Noise produced by a fuel cell power system shall be measured through the operating process; (startup to shutdown) in accordance with 7.3.13 and Table 3 in order to get the maximum value.

Corrections for background noise shall be made in accordance with ISO 3744.

The maximum corrected noise level and the corresponding operating conditions and output power level shall be reported.

8.3.17 Vibration level

Vibration produced by a fuel cell power system shall be measured through the operating condition mentioned below in accordance with 7.3.14 to find the maximum vibration level. The background vibration level shall be measured when the fuel cell power system is not in operation.

The vibration level shall be monitored during a start-up transient starting from the cold state. Vibration levels shall be measured through increasing power levels up to rated load. The vibration level shall be measured at steady-state rated load. The vibration shall also be monitored during a shutdown transient starting from rated load. Vibration levels shall also be measured during the shutdown transient until the fuel cell power system reaches the standby state or the cold state to find the maximum vibration level.

The maximum operating vibration level shall be reported. The background vibration level with the fuel cell power system not operating shall also be reported.

Corrections for the background vibration level shall be made for the maximum vibration level in accordance with the following procedure.

The difference between the reported maximum vibration level and the background vibration level shall be calculated in decibels (dB).

Calculate the correction to the reported maximum vibration level using Table 5.

If the difference is at more than 9 dB (maximum vibration level is higher than background by more than 9 dB), no correction is necessary.

If the difference is less than 3 dB, the background is too high for reliable measuring and shall be reduced.

For very low vibration systems, the maximum vibration level may be very low. The maximum vibration level may be below 10 dB. For these very low vibration systems, below 10 dB measured maximum vibration, no correction for background is necessary.

If the difference between the maximum operating vibration level and the non-operating background is between 3 dB and 10 dB, use Table 5 to compute the correction to the reported maximum vibration level.

Table 5 – Vibration correction factors

Difference of indicated value dB	3	4	5	6	7	8	9
Correction value dB	–3	–2	–2	–1	–1	–1	–1

NOTE 1 A difference of 10 dB or more indicates no significant influence of background vibration, and the correction is not necessary.

NOTE 2 A difference less than 3 dB implies that the background vibration is too large for reliable measurement.

8.3.18 Discharge water quality

Measure discharge water quality in accordance with 7.3.9 and Table 3.

9 Test reports

9.1 General

Test reports shall accurately, clearly and objectively present sufficient information to demonstrate that all the objectives of the tests have been attained. The reports shall contain all information developed in Clause 7. Three types of reports are required, summary, detailed, and full. Each type of report shall contain the same title page and a table of contents. For fuel cell systems tested in compliance with this part of IEC 62282, the summary report will be made available to interested parties.

9.2 Title page

The title page shall present the following information:

a) report identification number (optional);
b) type of report (summary, detailed or full);
c) authors of report;
d) entity conducting the test;
e) date of report;
f) location of test;
g) title of the test;
h) date and time of test;
i) fuel cell power system identification and manufacturer's name;
j) type of fuel used for the test with reference to appropriate gas reference table (Annex C).

9.3 Table of contents

For each type of report, a table of contents shall be provided.

9.4 Summary report

The summary report shall include the following information:

a) objective of the test;
b) description of the test, equipment and instruments;
c) all test results;
d) uncertainty level attached to each test result;
e) confidence level attached to each test result;
f) for determination of recovered heat, pressure and temperature of the heat recovery fluid;
g) conclusions as appropriate.

9.5 Detailed report

The detailed report shall include the following information in addition to the information contained in the summary report:

a) the type, specifications and operating configuration of the fuel cell power system and the process flow diagram showing the test boundary;
b) description of the arrangements, location and operating conditions of the equipment and instruments;

c) calibration results of instruments;
d) reference to the calculation method;
e) tabular and graphical presentation of the results;
f) discussion of the test and its results (i.e. comments and observations).

9.6 Full report

The full report shall include the following information in addition to the information contained in the detailed report.

a) Copies of original data sheets

Original data sheets shall include the following information in addition to measurement data:

1) date and time of the test run;
2) model number and measurement accuracy of instruments used for the test;
3) ambient test conditions;
4) name and qualifications of person(s) conducting the test;
5) full and detailed uncertainty analysis;
6) results of fuel analysis.

Annex A
(normative)

Guidance for uncertainty analysis

A.1 General

When reporting the result of a measurement of a physical quantity, it is obligatory that some quantitative indication of the quality of the result be given so that those who use it can assess its reliability. Therefore, uncertainty analysis is indispensable for a fuel cell power system performance test. The uncertainty can be analysed at pre-test and/or post-test.

A pre-test uncertainty analysis is recommended. The pre-test uncertainty analysis allows corrective action to be taken prior to the test, which will either decrease the uncertainty to an appropriate level consistent with the overall objective of the test or will reduce the cost of the test while still attaining the test uncertainty.

A post-test uncertainty analysis is mandatory. The uncertainty analysis will make use of empirical data to determine uncertainty of fuel cell power system performance. Uncertainty shall be indicated with a performance value (i.e. electrical efficiency, heat recovery efficiency and so on).

This annex serves as a guide for pre-test and post-test uncertainty calculations and shows an example of uncertainty analysis for electrical efficiency and is only provided for informative purposes, not as an explicit test result. The user of this part of IEC 62282 shall read, understand, and follow the ISO/IEC Guide for Expression of Uncertainty in Measurement (G.E.U.M) in order to accomplish a proper uncertainty analysis.

The uncertainty analysis for this standard shall be performed in accordance with the ISO/IEC G.E.U.M. This annex gives examples, but refer to the G.E.U.M. for explicit guidance.

A.2 Preparations

Uncertainty of fuel cell power system performance (i.e. electrical efficiency, etc.) can be computed by the uncertainties of the various parameters, as well as fuel cell power system performance.

Every measurement of the parameters is the combination of a true value plus a total measurement error. The total measurement error consists of systematic error and random error.

The total uncertainty of a parameter is the combination of uncertainty due to systematic error and random error.

In order to minimize the uncertainty of fuel cell power system performance, systematic uncertainties and random uncertainties of the parameters shall be minimized.

In order to minimize systematic uncertainty, higher accuracy instrumentation is recommended, because the accuracy of instrument (calibration uncertainty) is treated as systematic uncertainty in this part of IEC 62282. Careful selection of instrumentation is necessary.

In order to minimize random uncertainty, test procedures, test conditions and data collection methods shall be investigated. Random uncertainty is estimated as twice as much as standard deviation (2SD for 95 % coverage). Careful test planning is necessary before conducting the performance test.

Parameter measurements shall be as simultaneous as possible. Data recording using automated equipment will help to ensure simultaneous data sets. Test conditions shall be steady state for the performance tests.

Fluctuations of measurements (both short-term and long-term variations) and steady-state test conditions shall be confirmed by a preliminary test, before conducting the performance test. Steady state is defined in 8.1.3. Test run duration shall be decided according to the fluctuations of long-term parameter measurements. Test run duration shall include at least one cycle of long-term fluctuations.

During test run duration, at least 30 independent data sets of every parameter shall be measured to obtain a standard deviation of the data. Each data set shall be an average of measurements taken (i.e. for measurement of voltage) or an accumulation divided by measurement time (i.e. for flow rate of fuel).

In order to maintain independence of the data points, a minimum of 1 min between data sets is also required.

A.3 Basic assumptions

The guidance in this annex is based on the IEC/ISO G.E.U.M. The guidance herein is simplified for use with fuel cell systems, using assumptions consistent with their design as well as good testing practice dictated by this part of IEC 62282.

Basic assumptions include the following.

All systematic uncertainty sources are assumed normally distributed and are estimated as 2σ for 95 % coverage. In this part of IEC 62282, systematic uncertainty is defined as the calibration error or accuracy of an instrument, B.

At least 30 independent data points are taken for all parameters. If fewer than 30 independent data points are taken for one or more parameters, additional calculations are required. In this case, consult the G.E.U.M.

All random uncertainty sources are assumed normally distributed and estimated as $2S_{\overline{x}}$ of measurements, which is 95 % confidence coverage.

Total uncertainty, U_{95} is obtained by combining systematic uncertainty, B and random uncertainties of a measurement, $S_{\overline{x}}$ with the following equation.

$$U_{95} = \left[B^2 + (2S_{\overline{x}})^2\right]^{1/2}$$

which is equivalent to

$$U_{95} = 2\left[(B/2)^2 + (S_{\overline{x}})^2\right]^{1/2}$$

A.4 General approach

The following gives a step-by-step calculation procedure.

a) Define the measurement process

   1) Review test objectives and test duration.

      A preliminary test shall be carried out to decide test run duration, if necessary.

   2) List all independent measurement parameters and their nominal levels.

   3) List all calibrations and instrument settings that will affect each parameter. Be sure to check for uncertainties in measurement system components that affect two or more measurements simultaneously (correlated uncertainties).

   4) Define the functional relationship between the independent measurement parameters and the test result. (Define the equations for calculating fuel cell power system performance as given in the text.)

b) List primary error sources: make a complete and exhaustive list of all possible test uncertainty sources for all parameters.

c) Calculate or assign the absolute systematic and random uncertainty for each parameter.

   1) Absolute systematic uncertainty (B_i) is calculated by multiplying calibration accuracy by the nominal value of every parameter.

   2) Absolute random uncertainty ($2S_{xi}$) is twice as much as the standard deviation of parameter.

d) Propagate the systematic and random uncertainty for each parameter.

   1) The systematic and random uncertainty of the independent parameters is propagated separately all the way to the final result with following equation.

   2) This requires a calculation of the sensitivity factors, θ_i, either by differentiation or by computer perturbation with the functional relationship defined in step d)1) above.

$$B_R = \left[\sum (\theta_i B_{\overline{P}i})^2\right]^{1/2}$$

$$2S_R = \left[\sum (\theta_i 2S_{\overline{P}i})^2\right]^{1/2}$$

where

B_R is the systematic uncertainty component of a result;

$2S_R$ is the random uncertainty component of a result.

e) Calculate the total uncertainty.

   Calculation of uncertainty is done in accordance with following equation, combining the systematic and random uncertainties to get the total uncertainty.

$$U_{R95} = \left[(B_R)^2 + (2S_R)^2\right]^{1/2}$$

f) Prepare the report in accordance with Clause 9.

A.5 Example calculations

A.5.1 Uncertainty calculation for electrical efficiency

A.5.1.1 Definition of the measurement process

This example will focus on the calculation of electrical efficiency. The system is a 1 kW PEFC fuel cell system, with 0,1 kW electrical inputs from grid for parasitic load and fuel input. The system uses city gas fuel and provides 1,1 kW electrical power output at the terminals. Net electrical power output is 1 kW. City gas fuel is provided at the temperature of 298,15 K and pressure of 110 kPa. Oxidant (air) is provided at ambient temperature and pressure.

The fuel flow is measured with a precision mass flow meter and online sampling is used to compute the lower heating value of the fuel. Electrical output and electrical input are measured using a power kWh meter.

Test run duration was decided taking into account the long-term fluctuations of parameter measurements. Test run duration included five cycles of long-term fluctuation. During test run duration, 60 sets of 30 measurements of every parameter were obtained. Interval of every set of measurements was 1 min. Every value of parameter for calculating performance is the mean of 60 sets of 30 measurements.

All independent measurement parameters and their nominal levels of the total means of 60 sets of 30 measurements are listed in Table A.1, and calculation results based on the parameters of Table A.2 are shown in table A.3.

The electrical efficiency, η_e is defined as follows according to 8.3.4. In this example, fuel is gas and the term of energy carried by air is omitted as follows.

$$\eta_e = \frac{(P_{out} - P_{in})}{(q_{vf0} \times E_{fv})} \times 100$$

where

P_{out} is the electrical power output;

P_{in} is the electrical power input for parasitic load, etc.;

q_{v0} is the volumetric flow rate of fuel at the reference conditions,m^3/s;

E_{fv} is the input energy of the fuel per unit of volume, kJ/m^3 .

and, q_{vf0}, m^3/s, is calculated as follows:

$$q_{vf0} = q_{vf} \times (288{,}15/t_f) \times (p_f/101{,}3)$$

where

q_{vf} is the volumetric flow rate of the fuel at temperature t_f and pressure p_f, m^3/s;

q_{vf0} is the volumetric flow rate of fuel at the reference conditions, m^3/s;

t_f is the temperature of fuel;

p_f is the pressure of fuel;

and, the input energy of the fuel, E_{fv}, kJ/m^3 is calculated as follows:

$$E_{fv} = (Q_{f0} + h_f - h_{f0} + E_{pf})/M_o$$

where

Q_{f0} is the heating value of the fuel at reference conditions (kJ/mol);

h_f is the specific enthalpy of the fuel at temperature t_f (kJ/mol);

h_{f0} is the specific enthalpy of the fuel at the reference temperature t_0 (kJ/mol);

E_{pf} is the pressure energy of the fuel (kJ/mol);

M_o is the reference molar volume of ideal gas; 2,364 5 × 10^{-2} m^3/mol (at the reference temperature for this standard, 288,15 K).

The heating value of fuel, Q_{f0}, (kJ/mol), at the reference conditions is calculated as follows:

$$Q_{f0} = \sum_{j=1}^{N} x_j \, Q_{f0\,j}$$

where

Q_{f0j} is the heating value of component j at the reference temperature t_0 (kJ/mol);

x_j is the molar ratio of component j;

j is a component of the fuel;

N is the number of fuel gas constituent.

NOTE 1 Numerical values of Q_{f0j} are given in Table B.1.

The specific enthalpy of fuel, h_f (kJ/mol), is calculated from the equation

$$h_f = \sum_{j=1}^{N} x_j \, h_{fj}$$

where

h_{fj} is the specific enthalpy of component j at temperature t_f (kJ/mol);

x_j is the molar ratio of component j;

and, h_{fj} (kJ/mol) is given by the following equation

$$h_{fj} = (A_j \times t_f + (B_j/2\,000) \times t_f^2 + (C_j/3 \times 10^6) \times t_f^3) \times 10^{-3}$$

where

A_j, B_j and C_j are the constants of component j and given in Worksheet 1 of Annex B;

t_f is the temperature of fuel at test conditions (K).

NOTE 2 The specific enthalpy of the fuel, h_{f0}(kJ/mol) at the reference temperature is calculated with substituting t_0 for t_f in the above equation of h_{fj}.

The pressure energy of fuel, E_{pf} (kJ/mol) is calculated from the following equation:

$$E_{pf} = R \times t_0 \times \ln(p_f / p_0)$$

where

R is the universal gas constant (8,314 J/mol K);

t_0 is the reference temperature (288,15 K);

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

p_f is the pressure of fuel (kPa).

Table A.1 – Summary of measurement parameters and their nominal values

Parameter (P_i)	Description	Units	Nominal Value
q_{vf}	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m^3/s	6,6E-05
t_f	Temperature of fuel	K	298,15
p_f	Pressure of fuel	kPa	110
Fuel composition 13A	Methane	%	88
Fuel composition 13A	Ethane	%	6
Fuel composition 13A	Propane	%	5
Fuel composition 13A	Butane	%	2
P_{out}	Electric power output	kW	1,10
P_{in}	Electric power input for parasitic load, etc.	kW	0,10

Table A.2 – Nominal values of the calculation results

Calculated Results	Description	Units	Nominal Value
q_{v0}	Volumetric flow rate of fuel at the standard conditions	m^3/s	6,9E-05
Q_{f0}	Heating value of fuel at the standard conditions (LHV)	kJ/mol	926,4
h_f	Specific enthalpy of fuel at temperature t_f	kJ/mol	7,969
h_{f0}	Specific enthalpy of fuel at the standard temperature	kJ/mol	7,583
E_{pf}	Pressure energy of the fuel	kJ/mol	0,2036
E_{fv}	Input energy of the fuel	kJ/m^3	39203,2
η_e	Electrical efficiency	%	37,0

A.5.1.2 List elemental error sources

Elemental error sources can be estimated by judgement, calculated using pre-test data, or developed using calibration laboratory calculations. Elemental error sources for the various parameters in the example procedure are given in Table A.3.

Table A.3 – Elemental error sources for the various parameters

Parameter (P_i)	Description	Units	Nominal value	Elemental error sources
q_{vf}	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m^3/s	6,6E-05	Meter calibration errors, random errors
t_f	Temperature of fuel	K	298,15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors
Fuel composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random
Fuel composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random
Fuel composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random
Fuel composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random
P_{out}	Electric power output	kW	1,10	Revenue meter calibration errors, loop calibration errors, random errors
P_{in}	Electric power input for parasitic load etc.	kW	0,10	Revenue meter calibration errors, loop calibration errors, random errors

A.5.1.3 Calculate or assign the systematic and random uncertainty for each parameter

a) Systematic uncertainty

Calibration errors will account for the majority of the systematic uncertainty and so they are used with judgement as the absolute systematic uncertainty for those instruments where the calibration uncertainty is known. For instruments or instrument loops where calibration is ±1 % of full scale, the absolute uncertainty is calculated by multiplying 0,01 by the full-scale reading of the instrument. For instruments where the calibration uncertainty is ±1 % of the reading, the absolute uncertainty is calculated by multiplying 0,01 by the nominal reading. Different calibration uncertainties will require different numerical inputs.

Absolute systematic uncertainty (B_i) is calculated by multiplying calibration accuracy by the nominal value of every parameter in Table A.4.

b) Random uncertainty

Random uncertainty is estimated as twice as much as the standard deviation of parameter measurements.

Standard deviation (Sxi) of a parameter was calculated with the total mean of 60 sets of 30 measurements for a parameter during test run duration.

Absolute random uncertainty (2Sxi) is twice as much as the standard deviation on Table A.4. σ is standard deviation in percentage.

For post-test analysis, the actual standard deviation shall be used. If the random uncertainty is too high, additional test duration and additional data points shall lower the standard deviation.

Table A.4 – Absolute systematic uncertainty (B_i) and absolute random uncertainty (2Sxi)

Parameter (P_i)	Description	Units	Nominal value	Elemental error sources	Cal	Absolute systematic uncertainty (B_i)	σ (Sxi)	Absolute random uncertainty (2Sxi)
q_{vf}	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m^3/s	6,6E-05	Meter calibration errors, random errors	0,010	6,58E-07	0,010	1,32E-06
t_f	Temperature of fuel	K	298,15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	-	1,00E+00	0,015	2,00E+00
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	0,005	5,50E-01	0,001	2,20E-01
Fuel composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random	0,005	4,40E-01	0,001	1,76E-01
Fuel composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random	0,005	2,90E-02	0,001	1,16E-02
Fuel composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random	0,005	2,25E-02	0,001	9,00E-03
Fuel composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random	0,005	8,50E-03	0,001	3,40E-03
P_{out}	Electric power output	kW	1,10	Revenue meter calibration errors, loop calibration errors, random errors	0,005	5,50E-03	0,001	2,20E-03
P_{in}	Electric power input for parasitic load etc.	kW	0,10	Revenue meter calibration errors, loop calibration errors, random errors	0,005	5,00E-04	0,001	0,000 2

A.5.1.4 Propagate the systematic and random uncertainty for each parameter

The systematic and random uncertainty of the independent parameters are propagated separately all the way to the final result. In order to propagate the various uncertainties properly, the various sensitivities θ_i of each parameter P_i shall be calculated. The sensitivity of a particular parameter is calculated either by taking the partial differential of the parameter with respect to the result (the efficiency in this case) or by carrying out a computer perturbation of the data fields using small changes in each parameter independently to ascertain the change in the result for a small change in the parameter. In this example, the latter method was used. The change in parameters was 0,000 1 %. The systematic uncertainty and random uncertainty for each parameter shall be multiplied by the proper sensitivity in accordance with the following equations.

$$B_R = \left[\sum (\theta_i B_{\overline{P}i})^2\right]^{1/2}$$

$$2S_R = \left[\sum (\theta_i 2S_{\overline{P}i})^2\right]^{1/2}$$

where

B_{PI}	is absolute systematic uncertainty for the parameter P_i;
S_{PI}	is absolute standard deviation of the mean for parameter P_i;
B_R	is the systematic uncertainty component of a result;
$2S_R$	is the random uncertainty component of a result;
θ_i	is sensitivity coefficient for the parameter P_i;
$(\theta_i B_{\overline{Pi}})^2$	is absolute systematic uncertainty contribution for the parameter P_i;
$(\theta_i 2S_{\overline{Pi}})^2$	is random systematic uncertainty contribution for the parameter P_i.

The sensitivity coefficients for the parameters P_i are listed in Table A.5.

Propagated systematic uncertainty B_R and random uncertainty $2S_R$ are listed in Table A.6.

Table A.5 – Sensitivity coefficients for the parameter P_i

Delta X% 0,0001

Parameter for sensitivity		q_{vf}	t_f	p_f	Methane	Ethane	Propane	Butane	p_{out}	p_{in}
Parameter (P_i)	**Base**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**
q_{vf}	0,0000E+00	2,3672E-07	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
t_f	0,0000E+00	0,0000E+00	2,9815E-04	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
p_f	0,0000E+00	0,0000E+00	0,0000E+00	1,1000E-04	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
Methane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	8,8000E-05	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
Ethane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	5,8000E-06	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
Propane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	4,5000E-06	0,0000E+00	0,0000E+00	0,0000E+00
Butane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	1,7000E-06	0,0000E+00	0,0000E+00
p_{out}	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	1,1000E-06	0,000E+00
p_{in}	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	1,0000E-07
Calculated Results	**η e Nom**	**η e + Delta**	**η e + Delta**	**η e + Delta**	**η e + Delta**	**η e + Delta**	**η e + Delta**	**η e + Delta**	**η e + Delta**	**η e + Delta**
q_{v0}	0,2484	0,2484	0,2484	0,2484	0,2484	0,2484	0,2484	0,2484	0,2484	0,2484
Q_{f0}	926,4	926,4	926,4	926,4	926,4	926,4	926,4	926,4	926,4	926,4
h_f	7,969	7,969	7,969	7,969	7,969	7,969	7,969	7,969	7,969	7,969
h_{f0}	7,583	7,583	7,583	7,583	7,583	7,583	7,583	7,583	7,583	7,583
E_{pf}	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036
E_{fv}	39203,2	39203,2	39203,2	39203,3	39203,2	39203,2	39203,2	39203,2	39203,2	39203,2
η_e	37,0	37,0	37,0	37,0	37,0	37,0	37,0	37,0	37,0	37,0
Absolute Sensitivity (θ_i)	–	3,1031E+02	−3,3154E−04	7,9858E−02	3,8214E−01	5,7447E+00	7,8138E+00	2,1744E+01	7,0568E+01	3,3268E+02

Table A.6 — Propagated systematic uncertainty B_R and random uncertainty $1S_R$

Parameter (P_i)	Description	Units	Nominal value	Elemental error sources	Cal	Absolute systematic uncertainty (B_i)	σ (Sx_i)	Absolute random uncertainty ($2Sx_i$)	Absolute sensitivity (θ_i)	Absolute systematic uncertainty contribution $(\theta_i \cdot B_i)^2$	Absolute random uncertainty contribution $(\theta_i \cdot 2Sx_i)^2$
q_{vf}	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m³/s	6,58E-05	Meter calibration errors, random errors	0,010	6,58E-07	0,010	1,32E-06	1,1171E+06	5,3959E-01	2,1584E+00
t_f	Temperature of fuel	K	298,15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	-	1,00E+00	0,015	2,00E+00	-3,3154E-04	1,0992E-07	4,3966E-07
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	0,005	5,50E-01	0,001	2,20E-01	7,9858E-02	1,9291E-03	3,0866E-04
Fuel composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	4,40E-01	0,001	1,76E-01	3,8214E-01	2,8271E-02	4,5234E-03
Fuel composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	2,90E-02	0,001	1,16E-02	5,7447E+00	2,7755E-02	4,4407E-03
Fuel composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	2,25E-02	0,001	9,00E-03	7,8138E+00	3,0909E-02	4,9454E-03
Fuel composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	8,50E-03	0,001	3,40E-03	2,1744E+01	3,4159E-02	5,4654E-03
P_{out}	Electric power output	kW	1,10	Revenue meter calibration errors, loop calibration errors, random errors	0,005	5,50E-03	0,001	2,20E-03	7,0568E+01	1,5064E-01	2,4102E-02
P_{in}	Electric power input for parasitic load, etc.	kW	0,10	Revenue meter calibration errors, loop calibration errors, random errors	0,005	5,00E-04	0,001	0,0002	3,6964E+01	3,4159E-04	5,4654E-05
									$\Sigma(\theta_i \cdot B_i)2$ (*L*) $\Sigma(\theta_i \cdot 2Sxi)2$ (*R*)	8,1359E-01	2,2022E+00
									$B_R(L)$, $2S_R(R)$	9,0199E-01	1,4840E+00

Calculated results	Description	Units	Nominal value
q_{v0}	Volumetric flow rate of fuel at the standard conditions	m³/s	6,9E-05
Q_{f0}	Heating value of fuel at the standard conditions (LHV)	kJ/mol	926,4
h_f	Specific enthalpy of fuel at temperature t_f	kJ/mol	7,969
h_{f0}	Specific enthalpy of fuel at the standard temperature	kJ/mol	7,583
E_{pf}	Pressure energy of the fuel	kJ/mol	0,2036
E_{fv}	Input energy of the fuel	kJ/m³	39203,2
η_e	Electrical efficiency	%	37,0

A.5.1.5 Calculate the total uncertainty

The total absolute uncertainty of the result is computed by combining the absolute systematic uncertainty with the absolute random uncertainty in the following manner.

Total absolute uncertainty of the result, $U_{R95} = \sqrt{B_R^2 + (2S_R)^2}$

where

B_R is the propagation of systematic uncertainty components as a result;

$2S_R$ is the propagation of random uncertainty components as a result.

Per cent uncertainty of U_{R95} of electrical efficiency is obtained by dividing total absolute uncertainty with nominal value of electrical efficiency.

Total absolute uncertainty of the result U_{R95} and per cent uncertainty of U_{R95} of electrical efficiency are shown in Table A.7.

A.5.1.6 Prepare the report in accordance with Clause 9

The result of uncertainty analysis is expressed as follows, for example.

Electrical efficiency: 37,0 % ±1,7 %

Total uncertainty of electrical efficiency: 4,7 %.

Table A.7 – Total absolute uncertainty of the result U_{R95} and per cent uncertainty of U_{R95} of electrical efficiency

Uncertainty analysis for electric efficiency

Electrical efficiency: 37,0 ±1,7 %   Total uncertainty: ±4,7 %

Parameter (P_i)	Description	Units	Nominal value	Elemental error sources	Cal	Absolute systematic ucertainty (B_i)	σ (Sx_i)	Absolute random uncertainty ($2Sx_i$)	Absolute sensitivity (θ_i)	Absolute systematic uncertainty contribution $(\theta_i \cdot B_i)^2$	Absolute random uncertainty contribution $(\theta_i \cdot 2Sx_i)^2$
q_{vf}	Volumetric flow rate of fuel at temperature t_f and pressure p_f	m^3/s	6,58E-05	Meter calibration errors, random errors	0,010	6,58.E-07	0,010	1,32.E-06	1,1171E+06	5,3959E-01	2,1584E+00
t_f	Temperature of fuel	K	298,15	Temperature gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	-	1,00.E+00	0,015	2,00.E+00	-3,3154E-04	1,0992E-07	4,3966E-07
p_f	Pressure of fuel	kPa	110	Pressure gauge calibration errors, pressure transducer calibration errors, loop calibration errors, random errors	0,005	5,50.E-01	0,001	2,20.E-01	7,9858E-02	1,9291E-03	3,0866E-04
Fuel composition (13A)	Methane	%	88	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	4,40.E-01	0,001	1,76.E-01	3,8214E-01	2,8271E-02	4,5234E-03
Fuel composition (13A)	Ethane	%	6	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	2,90.E-02	0,001	1,16.E-02	5,7447E+00	2,7755E-02	4,4407E-03
Fuel composition (13A)	Propane	%	5	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	2,25.E-02	0,001	9,00.E-03	7,8138E+00	3,0909E-02	4,9454E-03
Fuel composition (13A)	Butane	%	2	Sampling errors, laboratory analysis errors, errors in tabular data, mass chromatograph calibration errors, random errors	0,005	8,50.E-03	0,001	3,40.E-03	2,1744E+01	3,4159E-02	5,4654E-03
P_{out}	Electric power output	kW	1,10	Revenue meter calibration errors, loop calibration errors, random errors	0,005	5,50.E-03	0,001	2,20.E-03	7,0568E+01	1,5064E-01	2,4102E-02
P_{in}	Electric power input for parasitic load, etc.	kW	0,10	Revenue meter calibration errors, loop calibration errors, random errors	0,005	5,00.E-04	0,001	0,0002	3,6964E+01	3,4159E-04	5,4654E-05
									$\Sigma(\theta_i \cdot B_i)2$ (*L*) $\Sigma(\theta_i \cdot 2Sx_i)2$ (*R*)	8,1359E-01	2,2022E+00
									$B_R(L)$, $2S_R(R)$	9,0199E-01	1,4840E+00

Total absolute uncertainty (U_{R95})	Percent uncertainty (U_{R95})
1,7	4,7%

Calculated results	Description	Units	Nominal value
q_{v0}	Volumetric flow rate of fuel at the standard conditions	m^3/s	6,9E-05
Q_{f0}	Heating value of fuel at the standard conditions (LHV)	kJ/mol	926,4
h_f	Specific enthalpy of fuel at temperature t_f	kJ/mol	7,969
h_{f0}	Specific enthalpy of fuel at the standard temperature	kJ/mol	7,583
E_{pf}	Pressure energy of the fuel	kJ/mol	0,2036
E_{fv}	Input energy of the fuel	kJ/m^3	39203,2
η_e	Electrical efficiency	%	37,0

Parameter for Sensitivity		q_{vf}	t_f	p_f	Methane	Ethane	Propane	Butane	P_{out}	P_{in}
Parameter (P_i)	**Base**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**	**0,0001% Delta**
q_{vf}	0,0000E+00	6,5755E-11	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
t_f	0,0000E+00	0,0000E+00	2,9815E-04	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
p_f	0,0000E+00	0,0000E+00	0,0000E+00	1,1000E-04	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
Methane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	8,8000E-05	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
Ethane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	5,8000E-06	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00
Propane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	4,5000E-06	0,0000E+00	0,0000E+00	0,0000E+00
Butane	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	1,7000E-06	0,0000E+00	0,0000E+00
P_{out}	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	1,1000E-06	0,0000E+00
P_{in}	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	0,0000E+00	1,0000E-07
Calculated results	**ηe Nom**	**ηe + Delta**	**ηe + Delta**	**ηe + Delta**	**ηe + Delta**	**ηe + Delta**	**ηe + Delta**	**ηe + Delta**	**ηe + Delta**	**ηe + Delta**
q_{v0}	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
Q_{f0}	926,4	926,4	926,4	926,4	926,4	926,4	926,4	926,4	926,4	926,4
h_f	7,969	7,969	7,969	7,969	7,969	7,969	7,969	7,969	7,969	7,969
h_{f0}	7,583	7,583	7,583	7,583	7,583	7,583	7,583	7,583	7,583	7,583
E_{pf}	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036	0,2036
E_{fv}	39203,2	39203,2	39203,2	39203,3	39203,2	39203,2	39203,2	39203,2	39203,2	39203,2
η_e	37,0	37,0	37,0	37,0	37,0	37,0	37,0	37,0	37,0	37,0
Absolute sensitivity (θ_i)	–	1,1171E+06	−3,3154E−04	7,9858E−02	3,8214E−01	5,7447E+00	7,8138E+00	2,1744E+01	7,0568E+01	3,3268E+02

Annex B
(normative)

Calculation of fuel heating value

Table B.1 – Heating values for components of natural gases at various combustion reference conditions for ideal gas

	Component	Heating value on a molar basis (kJ/mol)	Heating value on a mass basis (MJ/kg)
1	Methane	802,69	50,035
2	Ethane	1428,84	47,52
3	Propane	2043,37	46,34
4	n–Butane	2657,60	45,72
5	2–Methylpropane	2648,42	45,57
6	n–Pentane	3272,00	45,35
7	2–Metylbutane	3265,08	45,25
8	2.2–Dimethylpropane	3250,83	45,06
9	n–Hexane	3887,21	45,11
10	2–Methylpetane	3879,59	45,02
11	3–Methylpetane	3882,19	45,05
12	2.2–Dimethylbutane	3869,80	44,91
13	2.3–Dimethylbutane	3877,57	45,00
14	n–Hepetane	4501,72	44,93
15	n–Octane	5116,11	44,79
16	n–Nonane	5731,49	44,69
17	n–Decane	6346,14	44,60
18	Ethylene	1324,24	47,17
19	Propylene	1926,13	45,77
20	1–Butene	2540,97	45,29
21	Cis–2–Butene	2534,20	45,17
22	Trans–2–Butene	2530,50	45,10
23	2–Methylpropene	2524,30	44,99
24	1–Pentene	3155,59	44,99
25	Propadiene	1855,09	46,30
26	1.2–Butadiene	2461,82	45,51
27	1.3–Butadiene	2408,80	44,53
28	Acetylene	1256,94	48,27
29	Cyclopentane	3100,03	44,20
30	Methylcyclopentane	3705,86	44,03
31	Ethylcyclopentane	4320,92	44,01
32	Cyclohexane	3689,42	43,84
33	Methylcyclohexane	4293,06	43,72
34	Ethylcyclohexane	4911,49	43,77
35	Benzene	3169,56	40,58
36	Toluene	3772,08	40,94
37	Ethylbenzene	4387,37	41,33
38	o–Xylene	4376,48	41,22
39	Methanol	676,22	21,10
40	Methanethiol	1151,41	23,93
41	Hydrogen	241,72	119,91
42	Water	0	0
43	Hydrogen sulfide	517,95	15,20
44	Ammonia	316,86	18,61
45	Hydrogen cyanide	649,50	24,03
46	Carbon monoxide	282,91	10,10
47	Carbonyl sulfide	548,15	9,12
48	Carbon disulfide	1104,32	14,50
Temperature = 288,15 K. Reference: Table 3 and Table 4 in ISO 6976.			

Worksheet 1 – Calculation worksheet for energy of fuel gases

Temperature of fuel (t_f) 293 K (1)

Pressure of fuel (p_f) 103,325 kPa (2)

Component	Fuel composition (mol%)----(3)	Heating value of gas component (kJ/mol)----(4) (1)	Heating value of fuel component (Q_{f0}) (kJ/mol)	Constant A of gas component (2)	Constant B of gas component	Constant C of gas component	Specific enthalpy of fuel component at the reference temperature (kJ/mol) (6)	Specific enthalpy of fuel component at the reference temperature h_{f0} (kJ/mol)	Specific enthalpy of fuel component at temperature t_f (kJ/mol)-----(8)	Specific enthalpy of fuel component at the reference temperature t_f h_f (kJ/mol)
			(3) × (4) × 10^{-2}				Eq 1 (3)	(3) × (6) × 10^{-2}	Eq 2 (4)	(3) × (8) × 10^{-2}
Nitrogen	0,00	0,00	0,00	27,016	5,812	–0,289	8,0236	0,00	8,16	0,00
Oxygen	0,00	0,00	0,00	25,594	13,251	–4,205	7,8915	0,00	8,03	0,00
Carbon monoxide	0,00	282,91	0,00	26,537	7,6831	–1,1719	7,9561	0,00	8,10	0,00
Methane	88,00	802,69	706,37	14,146	75,496	–17,991	7,0669	6,22	7,23	6,37
Ethane	5,80	1 428,84	82,87	9,401	159,833	–46,229	8,9757	0,52	9,23	0,54
Propane	4,50	2 043,37	91,95	10,083	239,304	–73,358	12,2551	0,55	12,61	0,57
Butane	1,70	2 657,60	45,18	18,631	302,378	–92,943	17,1806	0,29	17,66	0,30
Hydrogen	0,00	241,72	0,00	29,062	–0,820	1,9903	8,3560	0,00	8,50	0,00
Water	0,00	0,00	0,00	30,204	9,933	1,117	9,1246	0,00	9,29	0,00
Total			(5) 926,37					(7) 7,58		(9) 7,77

(1) Reference ISO 6976
(2) Reference JANAF Thermochemical Tables D.R.Stull,H.Prophet published by NSRDS-NBS 37 (1965,1971).
(3) Eq1 = (A × 288,15 + B/2/10^3 × 288,15^2 + C/3/10^6 × 288,15^3) × 10^{-3}
(4) Eq2 = (A × (1) + B/2/10^3 × $(1)^2$ + C/3/10^6 × $(1)^3$) × 10^{-3}

Heating value(Q_{f0}) 926,37 kJ/mol（from (5)) (10)
Specific enthalpy of fuel component at temperature (h_f) 7,77 kJ/mol（from (9)) (11)
Specific enthalpy of fuel component at the reference temperature (h_{f0}) 7,58 kJ/mol（from (7)) (12)
Pressure energy of the fuel (E_{pf}) = 8,314 × 10^{-3} × 288,15 × L_n（(2)/101,325） 0,05 kJ/mol (13)

Total energy of the fuel (E_{fv}) = Q_{f0} + h_f – h_{f0} + E_{pf} = (10) + (11) – (12) + (13) = 926,60 kJ/mol

Worksheet 2 – Calculation worksheet for energy of air

Temperature of air (t_a) 300 K-------(1)

Pressure of air (p_a) 103,325 kPa----(2)

Component	Constant A of air 1)	Constant B of air	Constant C of air	Specific enthalpy of air at the reference temperature; h_{a0} (kJ/mol) (3)	Specific Enthalpy of fuel Component at Temperature t_a h_a (kJ/mol) (4)
				Eq 1 (2)	Eq 2 (3)
Air	27,434	6,180	–0,8987	8,1545	8,5002

1) Reference JANAF Thermochemical Tables D.R.Stull,H.Prophet published by NSRDS-NBS 37 (1965,1971).

2) Eq1 = $(A \times 288{,}15 + B/2/10^3 \times 288{,}15^2 + C/3/10^6 \times 288{,}15^3) \times 10^{-3}$

3) Eq2 = $(A \times (1) + B/2/10^3 \times (1)^2 + C/3/10^6 \times (1)^3) \times 10^{-3}$

Specific enthalpy of air at temperature t_a (h_a) 8,50 kJ/mol（from (4))------(5)

Specific enthalpy of air at the reference temperature (h_{a0}) 8,15 kJ/mol（from (3))------(6)

Pressure energy of the fuel (E_{pa}) = $8{,}314 \times 10^{-3} \times (1) \times L_n$（(2)/101,325） 0,05 kJ/mol---------------------(7)

Total energy of the air (E_{av}) = $Q_{a0} + h_a - h_{a0} + E_{af}$ = (5) – (6) + (7) = 0,39 kJ/mol

Annex C
(normative)

Reference gas

C.1 General

The reference gas tables given below are provided to allow the customer to compare the performances measured by himself, obtained with his own natural gas, with the performances advertised by the manufacturer, obtained with the manufacturer's natural gas. When a manufacturer and an increasing number of customers test the same equipment with different natural gases (and publish their test results), a database of adjustment factors can be progressively established to distinguish between natural gases. Eventually, a new customer should be able to find the adjustment factor in order to correct the advertised performances to his particular gas composition by referring to the closest reference gas.

C.2 Reference gases for natural gas and propane gas

A set of 14 reference gases for natural gas is provided in Table C.1, and a set of 17 reference gases for propane in Table C.2.

When a test gas is used, the reference gas closest to the test gas should be mentioned in the report.

Natural gas distribution systems generally include various sulphur compounds as odorants:

> Major sulphur compounds; Tetrahydrothiophene, Hydrogen sulphide (H_2S), Diethylsulphide (DES), Methylethylsulphide (MES), Dimethylsulphide (DMS), methylmercaptan (MM), iso-propylmercaptan (IPM), tertio-butylmercaptan (TBM), iso-butylmercaptan (IBM), 2-butylmercaptan (SBM), etc.

Table C.1 – Reference gas for natural gas

	A1	A2	B1	B2	C1	C2	D1	D2	E1	E2	F1	F2	G1	G2
CH4	66,2	67,2	63,0	82,4	65,1	74,9	75,6	97,2	88,9	71,7	92,0	85,7	83,4	72,0
C2H6	5,0	1,7	11,7	0,0	8,3	3,3	11,7	0,0	10,0	15,0	1,7	13,3	6,7	13,3
C3H8	0,7	3,3	2,0	0,0	4,0	3,3	0,7	1,3	0,0	2,7	6,0	0,7	4,7	5,3
C4H10	0,2	0,0	0,0	1,0	0,7	1,0	0,5	0,2	0,0	0,3	0,2	0,2	1,5	1,3
C5H12	0,1	0,0	0,0	0,7	0,6	0,4	0,3	0,1	0,0	0,2	0,1	0,1	1,0	0,9
C6+	0,1	0,0	0,0	0,3	0,3	0,3	0,2	0,1	0,0	0,1	0,1	0,1	0,5	0,4
CO2	7,8	10,0	5,6	2,2	5,6	1,1	8,9	1,1	1,1	3,3	0,0	0,0	0,0	2,2
N2	20,0	17,8	17,8	13,3	15,6	15,6	2,2	0,0	0,0	6,7	0,0	0,0	2,2	4,4
LHV (kWh/m^3)	7,84	7,86	8,89	9,01	9,66	9,58	10,21	10,19	10,65	10,77	11,19	11,26	11,92	11,96
LHV (MJ/m^3)	28,21	28,30	32,01	32,43	34,77	34,48	36,76	36,68	38,34	38,77	40,30	40,55	42,93	43,07
HHV (kWh/m^3)	8,69	8,71	9,84	9,99	10,67	10,59	11,30	11,31	11,81	11,90	12,39	12,47	13,17	13,20
HHV (MJ/m^3)	31,27	31,36	35,41	35,96	38,40	38,14	40,67	40,72	42,51	42,85	44,62	44,90	47,42	47,50

Table C.2 – Reference gas for propane gas

	1A	1B	1C	1D	1E	2A	2B	2C	2D	3A	3B	3C	3D	3E	3F	3G	3H
C2H6	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	0,0	5,0	5,0	0,0	0,0	5,0	0,0
C3H8	100,0	90,0	90,0	80,0	80,0	70,0	70,0	60,0	60,0	50,0	50,0	40,0	40,0	20,0	20,0	0,0	0,0
C4H10	0,0	5,0	10,0	15,0	20,0	25,0	30,0	35,0	40,0	45,0	50,0	55,0	60,0	75,0	80,0	95,0	100,0
LHV (kWh/m^3)	28,22	28,25	29,14	29,14	30,06	30,09	30,98	31,00	31,90	31,92	32,82	32,84	33,73	34,68	35,57	36,52	37,41
LHV (MJ/m^3)	101,58	101,69	104,90	105,00	108,21	108,31	111,52	111,62	114,83	114,92	118,13	118,23	121,44	124,85	127,06	131,47	134,68
HHV (kWh/m^3)	28,94	25,96	26,80	26,82	27,65	10,59	28,51	28,53	29,39	29,38	30,22	30,24	31,07	31,95	32,78	33,66	34,49
HHV (MJ/m^3)	93,38	93,47	96,46	96,55	99,54	99,63	102,62	102,71	105,70	105,78	108,77	108,86	111,85	115,02	118,01	121,17	124,16

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