

Fuel cell technologies —

Part 3-2: Stationary fuel cell power systems — Performance test methods

The European Standard EN 62282-3-2:2006 has the status of a
British Standard

ICS 27.070

National foreword

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The UK participation in its preparation was entrusted to Technical Committee GEL/105, Fuel cell technologies, which has the responsibility to:

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- present to the responsible international/European committee any enquiries on the interpretation, or proposals for change, and keep UK interests informed;
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Foreword

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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 systems – Performance test methods

1 Scope

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

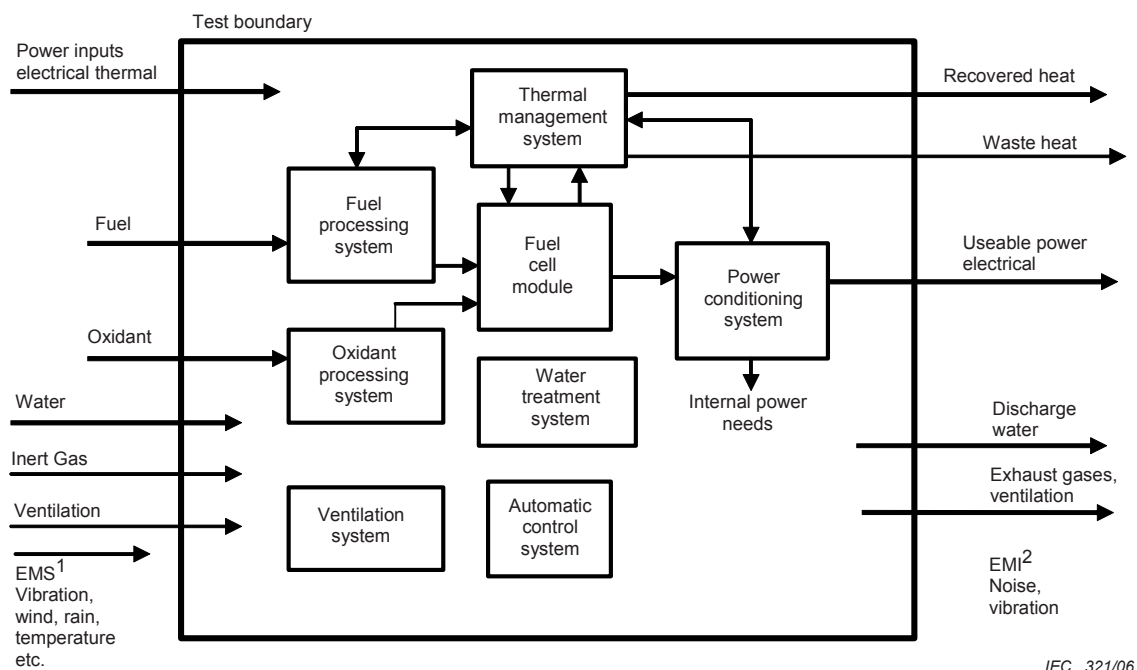
- power output under specified operating and transient conditions;
- electrical and thermal efficiency under specified operating conditions;
- environmental characteristics; for example, gas emissions, noise, etc. under specified operating and transient conditions.

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 electric 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 electric 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 interval 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_{HR1}	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
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
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
E	Input energy and power	
E_{fv}	Input energy of the fuel	kJ/m ³
E_{pf}	Pressure energy of the fuel	kJ/mol
E_{av}	Input energy of the oxidant (air)	kJ/m ³
E_{pa}	Pressure energy of the oxidant (air)	kJ/mol
Q_{in}	Input total power supplied by fuel and oxidant	kJ/s
η	Efficiency	
η_e	Electrical efficiency	%
η_{th}	Heat recovery efficiency	%
η_{total}	Overall energy efficiency	%
V	Voltage	
V_{out}	Voltage of electrical power output	V, kV
V_{in}	Voltage of electrical power input	V, kV
I	Current	
I_{out}	Current of electrical power output	A
I_{in}	Current of electrical power input	A
λ	Power factor	
λ_{out}	Power factor of electrical power output	--
λ_{in}	Power factor of electrical power input	--
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.		

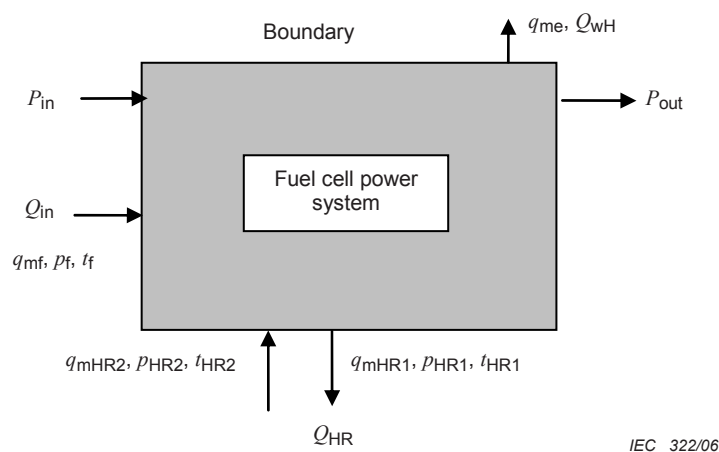


Figure 2 – Symbol diagram

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: $t_0 = 288,15 \text{ K (15 °C)}$

Reference pressure: $p_0 = 101,325 \text{ kPa}$

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:

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

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	SO _x , NO _x 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, SO_x, NO_x, CO₂, 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.