IEC 63277

Edition 1.0 2021-11

INTERNATIONAL STANDARD

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Binary power generation systems with capacity less than 100 kW – Performance test methods

IEC 63277:2021-11(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ICS 27.190

ISBN 978-2-8322-1046-6

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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BINARY POWER GENERATION SYSTEMS WITH CAPACITY LESS THAN 100 KW – PERFORMANCE TEST METHODS

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

Draft	Report on voting
126/35/FDIS	126/38/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

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INTRODUCTION

This document deals with the performance test methods for binary power generation systems.

Binary power generation systems are capable of generating electric power even with a relatively low temperature heat source, such as factory waste heat as well as renewable energy, such as hot spring water, geothermal heat, solar heat, etc..

The system utilizes the heat of said heat source by transferring it to a working fluid via a heat transport medium, instead of directly heating working fluid. Hence, it is called “binary system.”

By standardizing the performance measuring method of binary power generation systems, energy conservation performance can be assessed legitimately, and it will also be reflected in energy saving measures based on actual use. Increase of suppliers motivation for realizing high energy saving performance is expected, and energy saving products will be promoted around the world.

In addition, the world demand for binary power generation systems is also rising, and it is expected to grow rapidly in the future.

BINARY POWER GENERATION SYSTEMS WITH CAPACITY LESS THAN 100 KW – PERFORMANCE TEST METHODS

1 Scope

This document specifies the performance test methods for binary power generation systems.

It defines the normalized test conditions and estimates the power generation efficiency of binary power generation systems.

It specifies the binary power generation systems having heating medium of non-pressurized hot water, with a maximum temperature less than 100 °C created by renewable energy or wasted heat in the industrial field and cold water as cooling medium.

It is applied to binary power generation systems with electric power generation capacity of less than 100 kW.

This document specifies performance testing, the standard conditions and the test methods for determining the electric power output and power generation efficiency of binary power generation systems.

It includes heating conditions (temperature, flow rate) and cooling conditions (temperature, flow rate).

The requirements of testing and rating contained in this document are based on the use of matched assemblies.

This document does not include binary power generation systems more than 100 kW in electric power generation capacity.

The subject heating medium here is non-pressurized hot water with a temperature of less than 100 °C.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
binary power generation system
consists of five main components, i.e., an evaporator, a condenser, a working fluid pump, an expander and a generator, and a system in which a working fluid having a low boiling point is heated and evaporated by hot water, and the expander is driven by the working fluid gas to generate electricity

3.2
working fluid
medium used within the thermodynamic cycle that receives heat from the heat source via a heat transport medium and produces power by fluid expansion

3.3
heat source
supplies heat to drive the system

Note 1 to entry: This power generation system utilizes factory waste heat, hot spring water, geothermal heat and solar heat as heat sources from which it extracts heat with hot water (heat transfer medium) and thereby heats the working fluid through an evaporator to generate vapour.

3.4
cooling source
releases heat taken from the system by the cooling medium

Note 1 to entry: In this system, the working fluid is cooled by cold water (heat transfer medium) through heat exchanger (condenser) to generate a super cooled liquid; the heat received from the system is released into cooling source of ground water, river water, the atmosphere, etc.

3.5
evaporator
heat exchanger that heats and evaporates working fluid liquid by using hot water

3.6
condenser
heat exchanger that cools and condenses working fluid gas by using cold water

3.7
working fluid pump
fluid machine for sending working fluid liquid by the action of pressure with mechanical energy from condenser to evaporator

3.8
expander
machine that generates power by expanding a high-pressure working medium (working fluid vapour) heated with an evaporator and thereby driving a generator

Note 1 to entry: More specifically, high-pressure medium vapour taken in from the expander's inlet internally expands and then is discharged from the outlet port as low-pressure medium vapour; this process converts fluid energy into mechanical power.

Note 2 to entry: Generally, expanders are categorized according to their expansion mechanism, into kinetic type (centrifugal, axial, etc.) and displacement type (reciprocating, rotary, scroll, screw, etc.), and are selected depending on operating conditions and capacity range.

3.9
grid-connected inverter
module that converts high-frequency AC (Alternating Current) from a power generator into DC (Direct Current), and then converts that DC into high-quality AC for connecting to power grid

4 Construction, power of binary power generation system

4.1 General construction of binary power generation system

The **binary power generation system** consists of **evaporator**, **expander**, **condenser**, **working fluid pump**, and **generator** as shown in Figure 1.

A system in which a **working fluid** having a low boiling point is heated by the hot water and the **expander** is driven by the **working fluid** gas to generate electricity. The **heat source** is hot water and **cooling source** is cooling water. See Annex A for the informative specification for **grid-connected inverter.**

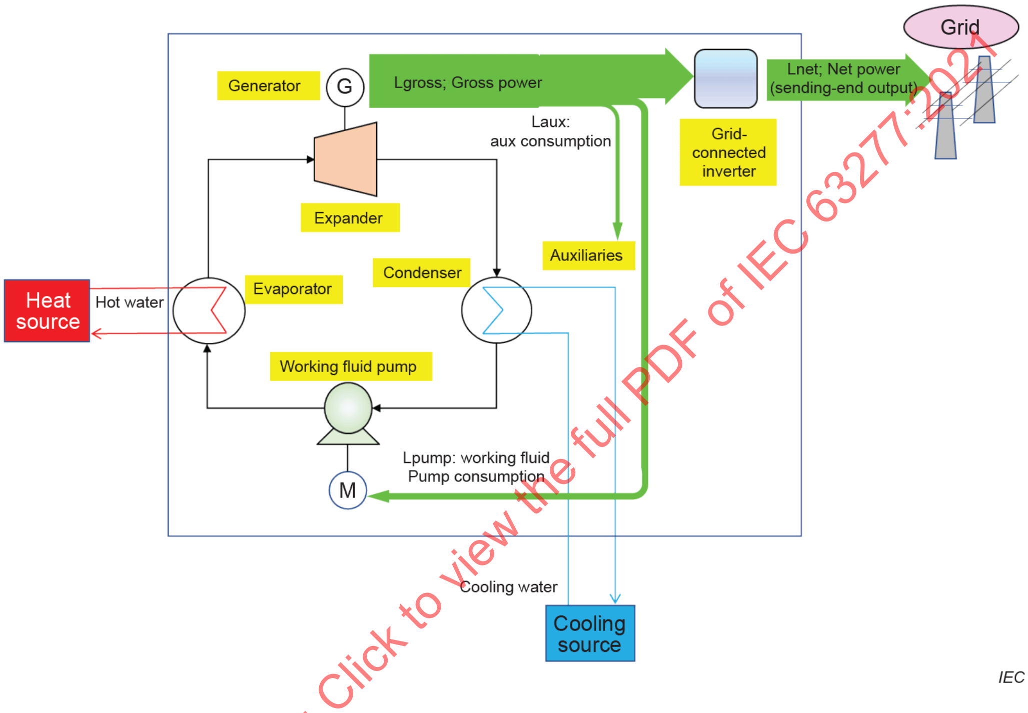

Figure 1 – Binary power generation system

4.2 Net power (Sending-end output) / Gross power (Generating power)

The sending-end output shall be the net power output of the system deducting the internal power consumed, such as the **working fluid pump**, **grid-connected inverter**, auxiliaries in the system from the gross power. And the gross power output shall be from the **generator** terminal.

5 Test condition

5.1 General test condition

General test conditions from Test 1 to Test 6 are shown in Table 1. Moreover, the tests provide a validation of nominal performance declared by the manufacturer datasheet (test condition 7).

All the measured values of Y1 kW to Y6 kW shall be recorded, unless specifically required by the manufacturer.

The generating power is measured with a combination of 6 temperature points.

Table 1 – Test conditions

Test	Item	Hot water temperature	Hot water flow rate	Cooling water temperature	Cooling water flow rate	Tolerance	Measured net power
1	5.2	90 °C ± 1 °C	20 l/min/kW ± 1 l/min/kW	20 °C ± 1 °C	30 l/min/kW ± 1,5 l/min/kW	within ±10 % declared by manufacturer brochure	Y1 kW To be compared with value declared by manufacturer brochure
2	5.1	80 °C ± 1 °C	20 l/min/kW ± 1 l/min/kW	20 °C ± 1 °C	30 l/min/kW ± 1,5 l/min/kW	–	Y2 kW
3	5.1	70 °C ± 1 °C	20 l/min/kW ± 1 l/min/kW	20 °C ± 1 °C	30 l/min/kW ± 1,5 l/min/kW	–	Y3 kW
4	5.1	90 °C ± 1 °C	20 l/min/kW ± 1 l/min/kW	30 °C ± 1 °C	30 l/min/kW ± 1,5 l/min/kW	–	Y4 kW
5	5.1	80 °C ± 1 °C	20 l/min/kW ± 1 l/min/kW	30 °C ± 1 °C	30 l/min/kW ± 1,5 l/min/kW	–	Y5 kW
6	5.1	70 °C ± 1 °C	20 l/min/kW ± 1 l/min/kW	30 °C ± 1 °C	30 l/min/kW ± 1,5 l/min/kW	–	Y6 kW
7	5.2	As specified in manufacturer brochure, °C	As specified in manufacturer brochure, l/min/kW	As specified in manufacturer brochure, °C	As specified in manufacturer brochure, l/min/kW	within ±10 % declared by manufacturer brochure	Y7 kW To be compared with value declared by manufacturer brochure

5.2 Rated test condition

5.2.1 General

The rated values (performance) shall be evaluated under the conditions of Test 1 in Table 1, at hot water temperature of 90 °C ± 1 °C and cooling water temperature of 20 °C ± 1 °C.

If the manufacturer defines the rated value under its own operating conditions other than the specified test conditions, the manufacturer shall specify the test conditions as shown in Test 7 of Table 1, and evaluated as rated value.

5.2.2 Tolerance of the rated net power

The measured rated net power shall be within ±10 % of rated net power stated in the specification brochure of the manufacturer.

5.3 Accuracy of instruments used for measurement

5.3.1 Thermometer

The accuracy of a thermometer used for measurement shall be ± 0,1 °C.

5.3.2 Flowmeter

The accuracy of a flowmeter used for measurement shall be ± 2 %.

5.3.3 Three-phase power meter

The accuracy of a three-phase power meter used for measurement shall be ± 0,2 %.

5.3.4 Calibration

Calibration shall be conducted according to the calibration standards of each measuring instrument for ensuring the traceability.

6 Measurement and calculation method of power output and power generation efficiency

6.1 Measurement method of net power (sending-end output)

The performance measuring method of the **binary power generation system** is shown in Figure 2.

The net power shall be measured under the test conditions described in 5.1 and 5.2.

The net power (sending-end power) shall be measured after the **grid-connected inverter**. It can be also obtained from the gross power measured after the **generator** deducting all of the internal power consumed, such as the **working fluid pump**, **grid-connected inverter**, and auxiliaries in the system.

Measurement begins after reaching steady state operation.

The system is considered in steady state when measured test condition quantities are within the accuracy of the stated range, and power output measured fluctuation is stable.

In the steady state, power generation is performed at the set temperature and flow rate, and after 10 min of stable operation, measurements are carried out 3 times. In each measurement, the measured quantities of temperature, flow rate and output power shall be mean value of sampled data for 2 min.

When the test conditions are changed, the measurement shall be started after reaching the steady state under the new condition.

In order to minimize the influence due to the fluctuation of the test conditions, carry out the measurements as simultaneously as possible.

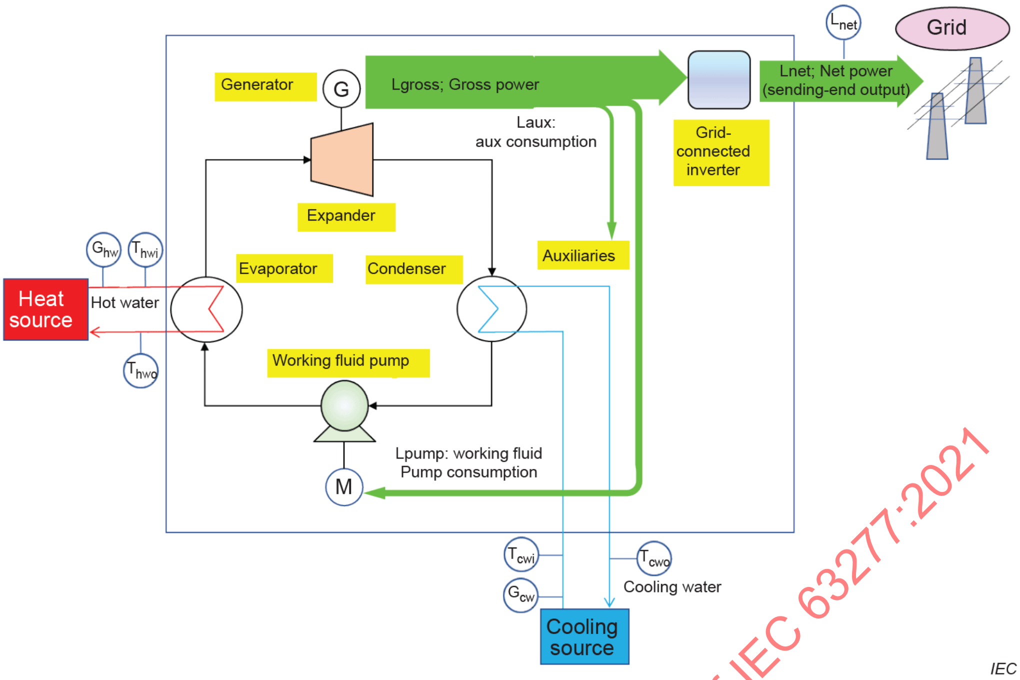

Figure 2 – Performance measuring method

6.2 Measurement method of flow rate and temperature of hot water

6.2.1 Temperature measurement of hot water

Temperature of the hot water shall be measured in the following way.

A resistance thermometer or a thermistor shall be inserted into a protective tube during the measurement.

In case of using a thermocouple which has thermal contacts, it shall be calibrated with the wire for the expected temperature range.

The temperature of hot water shall be measured at a distance of 30 cm or less from the inlet flange of the **evaporator** and at a point of 1/3 of the diameter of the hot water inlet pipe as shown in Figure 3.

The protection tube of the thermometer shall be thin, the diameter shall be small, the surface shall be practically usable for oxide or corrosion protection. The interior of the tube is filled with suitable filling material. During reading, the thermometer shall not be removed from the measuring object or protective tube.

Items to be checked before measurement are:

- Insulate sufficiently the protruding portion connected to the vicinity of the insertion portion so that the temperature of the hot water and protective tube are at the same temperature,
- The sensor of the temperature measuring device and the thermometer protective tube are well immersed in the hot water to be measured, and,
- The thermometer protective tube shall not prevent the normal flow.

6.2.2 Flow rate measurement of hot water

The flow rate of hot water is measured or calibrated by a measuring instrument, such as an electromagnetic flowmeter, a Coriolis (mass) flowmeter, a float type flowmeter, a vortex flowmeter, an ultrasonic flowmeter and an orifice flowmeter. A thermal flowmeter should not be used.

An electromagnetic flowmeter or an ultrasonic flowmeter which is less susceptible to vibration, can be used when the vibration affects the measurement.

In order to unify the flow velocity distribution, a straight part of pipe can be provided at the upstream part of the measuring instrument. The length of the straight part of pipe can be 5 times or more the pipe diameter as shown in Figure 3.

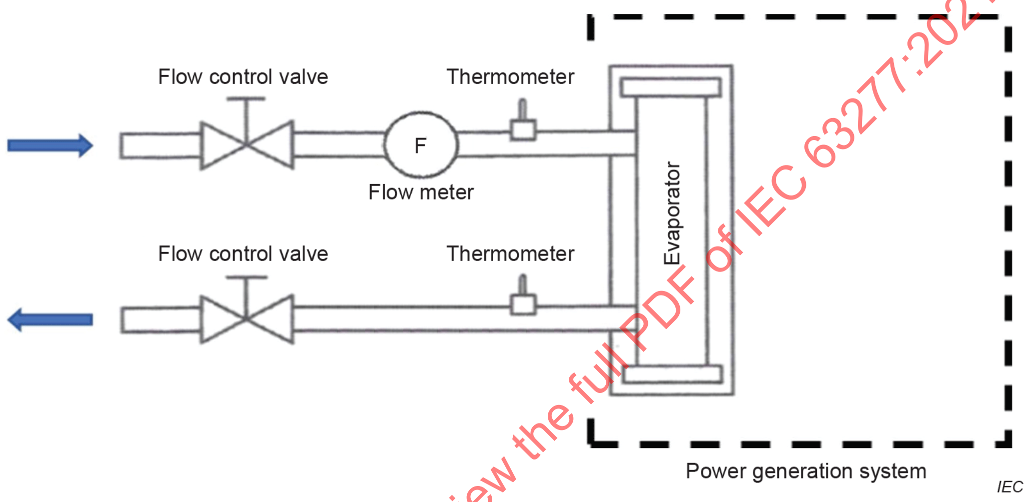

Figure 3 – Example of arrangement of hot water flowmeter

6.3 Measurement method of flow rate and temperature of cooling water

The measurement method described in 6.2 shall be applied.

6.4 Calculation method of power output and power generation efficiency

6.4.1 Receiving heat amount from hot water in the evaporator Q_H (kW)

The amount of receiving heat Q_H is calculated by formula (1) from the temperature and flow rate of hot water sent to the **evaporator**.

$$Q_H = C_{pw} \times G_{hw} \times (T_{hwi} - T_{hwo}) \quad (1)$$

where

C_{pw} is the specific heat of hot water（kJ/kg·K）；

G_{hw} is the hot water mass flow rate（kg/sec）；

T_{hwi} is the hot water temperature of evaporator inlet (°C);

T_{hwo} is the hot water temperature of evaporator outlet (°C).

6.4.2 Net power (sending-end output) L_{net} (kW)

The net power (sending-end power) shall be measured directly as described in 6.1.

The net power can be also obtained from the gross power measured after the **generator** deducting all of the internal power consumed, such as the **working fluid pump**, **grid-connected inverter**, auxiliaries in the system, shown as formula (2).

$$L_{\mathrm{net}} = L_{\mathrm{gross}} - L_{\mathrm{pump}} - L_{\mathrm{aux}} \tag{2}$$

where

L_{net} is the net power (sending-end output) (kW);

L_{gross} is the gloss power (output of the power generator) (kW);

L_{pump} is the power consumption of the working fluid pump (kW);

L_{aux} is the power consumption of grid-connected inverter, auxiliaries in the system (kW).

6.4.3 Power generation efficiency η_{eout}

The power generation efficiency of the system is calculated by formula (3). See Annex B for the example of calculation.

$$\eta_{\mathrm{eout}} = \frac{L_{\mathrm{net}}}{Q_{\mathrm{H}}} \times 100(\%) \tag{3}$$

7 Marking documentation

7.1 Marking on the product

A **binary power generation system** shall be marked with the following items in a manner that is not easily erased and in a location that is easily visible in normal installation.

a) Name of the system
b) System model
c) Name of the working medium or its symbol
d) Rated net power (sending-end output)
e) Rated output voltage
f) Rated output current
g) Rated output frequency
h) Number of output phases (single or three phases)
i) Manufacturer name
j) Date of production
k) Serial number or lot number of the system

7.2 Description in the technical documentation

The following items shall be appropriately specified in technical documentation. See also Annex C.

a) Name of the system
b) System model
c) Name of the working medium or its symbol

d) Design pressure (high pressure and low-pressure section)

e) Rated operating conditions

Hot water temperature (T_{hwi}, T_{hwo})

Hot water flow rate (G_{hw})

Cooling water temperature (T_{cwi}, T_{cwo})

Cooling water flow rate (G_{cw})

f) Rated net power (sending-end output) (L_{net})

g) Rated output voltage

h) Rated output current

i) Rated output frequency

j) Number of output phases (single or three phases)

k) Operating range (hot water and cooling water temperature)

Annex A
(informative)

Specification of grid-connected inverter for power generation systems

A.1 Outline of the equipment

This is a device that converts the DC power generated by the **generator** to the same rectified AC power as the commercial power supply. As shown in Figure A.1, the **grid-connected inverter** consists of a converter section, an inverter section, a control function section, and a protection function section.

A.2 Required specification

It is required to convert the power converted to direct current by the inverter to rectified AC power. And the rectified AC power shall comply with international standards and national standards.

- The total current distortion factor shall be 5 % or less.
- Each order current distortion factor shall be 3 % or less.
- To cope with voltage and frequency of commercial power supply of each country.
- To be compatible with rotary electric **generators**.
- Capable of preventing backward flow.
- Equipped with countermeasures against instantaneous voltage fluctuation and frequency fluctuation.
- Equipped with measures to prevent DC current leakage.

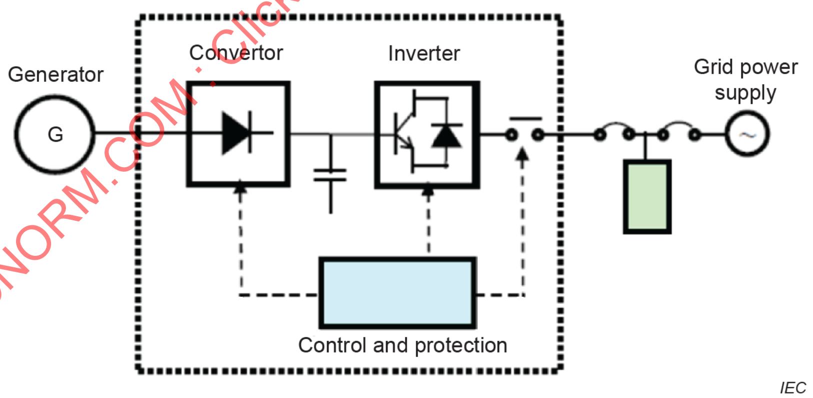

Figure A.1 – Interconnection circuit diagram using grid-connect inverter