

TECHNICAL SPECIFICATION

Photovoltaic systems – Power conversion equipment performance – Energy evaluation method

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TECHNICAL SPECIFICATION

Photovoltaic systems – Power conversion equipment performance – Energy evaluation method

INTERNATIONAL
ELECTROTECHNICAL
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**PHOTOVOLTAIC SYSTEMS –
POWER CONVERSION EQUIPMENT PERFORMANCE –
ENERGY EVALUATION METHOD**

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Technical Specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC TS 63156, which is a Technical Specification, has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

The text of this Technical Specification is based on the following documents:

Draft TS	Report on voting
82/1755/DTS	82/1801A/RVDTS

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

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

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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- withdrawn,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

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INTRODUCTION

The performance of a photovoltaic power generation system is influenced by various factors, such as meteorological conditions, installation environment (e.g. shade sources, soiling), design, and so on. The performance of a power conversion equipment is one of the significant indices for evaluating the performance of a PV system. IEC 61683 and IEC 62891 describe procedures for measuring the static (constant) conversion efficiency of power conversion equipment and MPPT efficiency, respectively. However, the standards do not define conversion efficiency under dynamic changes in factors such as meteorological changes, installation environment changes or temporal changes.

The CEC efficiency test protocol and EN 50530 define dynamic performance tests and procedures partially, but do not define a calculation procedure for evaluating the quantity of energy produced by a PV system. IEC TS 61724-3 describes a procedure for measuring and analysing the energy production of a specific photovoltaic system relative to the production expected for the same system from actual weather conditions for a certain period, but does not define the procedure for measuring the performance of power conversion equipment under actual environments.

Since there are areas where meteorological conditions, especially irradiance, change greatly and could affect the performance of power conversion equipment, a performance evaluation method under dynamic conditions needs to be defined. This document describes the procedure for evaluating the dynamic performance and energy production efficiency of power conversion equipment in a particular location using site-specific solar profiles.

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PHOTOVOLTAIC SYSTEMS – POWER CONVERSION EQUIPMENT PERFORMANCE – ENERGY EVALUATION METHOD

1 Scope

This document describes the procedure for evaluating the energy conversion performance of stand-alone or grid-connected power conversion equipment (PCE) used in PV systems. This procedure includes the calculation of inverter performance to anticipate the energy yield of PV systems. This evaluation method is based on standard power efficiency calculation procedures for PCE found in IEC 61683 and IEC 62891, but provides additional methods for evaluating the expected overall energy efficiency for a particular location given solar load profiles. This document can be used as the energy evaluation method for PCE in IEC TS 61724-3, which defines a procedure for evaluating a PV system's actual energy production relative to its modeled or expected performance.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61683, *Photovoltaic systems – Power conditioners – Procedure for measuring efficiency*

IEC TS 61836, *Solar photovoltaic energy systems – Terms, definitions and symbols*

IEC 62891, *Maximum power point tracking efficiency of grid connected photovoltaic inverters*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61836 as well as the following 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

irradiance

G

electromagnetic radiated power per unit area

Note 1 to entry: Unit: $W \cdot m^{-2}$.

3.2

in-plane irradiance

G_l

total irradiance on the plane of a PV cell or module

Note 1 to entry: Unit: $W \cdot m^{-2}$.

3.3 rate of change of irradiance

 R

change in irradiance amount during 1 s

Note 1 to entry: Unit: $W \cdot m^{-2} \cdot s^{-1}$.

3.4 rated input voltage

 $V_{DC,r}$

rated input voltage specified by the manufacturer, to which other data sheet information refers

Note 1 to entry: Unit: V.

3.5 rated input power

 $P_{DC,r}$

rated input power of the power conversion equipment, which can be converted under continuous operating conditions

Note 1 to entry: Unit: W.

3.6 rated output voltage

 $V_{AC,r}$

utility grid voltage to which other data sheet information refers

Note 1 to entry: Unit: V.

3.7 rated output power

 $P_{AC,r}$

active power that the power conversion equipment can output during continuous operation

Note 1 to entry: Unit: W.

3.8 PV simulator MPP-Power

 $P_{MPP,PVS}$

MPP power provided by the PV simulator

Note 1 to entry: Unit: W.

3.9 input power

 P_{DC}

measured input power of the device under test

Note 1 to entry: Unit: W.

3.10 PV simulator MPP voltage

 $V_{MPP,PVS}$

MPP voltage provided by the PV simulator

Note 1 to entry: Unit: V.

**3.11
input voltage**

V_{DC}
measured input voltage of the device under test

Note 1 to entry: Unit: V.

**3.12
PV simulator MPP current**

$I_{MPP,PVS}$
MPP current provided by the PV simulator

Note 1 to entry: Unit: A.

**3.13
input current**

I_{DC}
measured input current of the device under test

Note 1 to entry: Unit: A.

**3.14
output power**

P_{AC}
measured AC output power of the device under test

Note 1 to entry: Unit: W.

**3.15
output voltage**

V_{AC}
measured AC voltage of the device under test

Note 1 to entry: Unit: V.

**3.16
output current**

I_{AC}
measured AC output current of the device under test

Note 1 to entry: Unit: A.

**3.17
MPPT efficiency**

η_{MPPT}
ratio of the energy drawn by the device under test within a defined measuring period T_M to the energy provided theoretically by the PV simulator at the maximum power point (MPP):

$$\eta_{MPPT} = \frac{\int_0^{T_M} P_{DC}(t) dt}{\int_0^{T_M} P_{MPP}(t) dt} \quad (1)$$

where

η_{MPPT} is MPPT efficiency;

$P_{DC}(t)$ is the instantaneous value of the power drawn by the device under test, in kW;

$P_{MPP}(t)$ is the instantaneous value of the MPP power provided theoretically by the PV simulator, in kW.

Note 1 to entry: Unit: dimensionless, usually expressed as a percentage, %.

3.18 energy conversion efficiency

η_{CONV}

ratio of the energy delivered by the device under test at the AC terminal within a defined measuring period T_M to the energy received by the device under test at the DC terminal:

$$\eta_{CONV} = \frac{\int_0^{T_M} P_{AC}(t) dt}{\int_0^{T_M} P_{DC}(t) dt} \quad (2)$$

where

η_{conv} is the energy conversion efficiency;

$P_{AC}(t)$ is the instantaneous value of the delivered power at the AC terminal of the device under test, in kW;

$P_{DC}(t)$ is the instantaneous value of the received power at the DC terminal of the device under test, in kW.

Note 1 to entry: Unit: dimensionless, usually expressed as a percentage, %.

3.19 total energy conversion efficiency

η_t

product of the energy conversion efficiency and MPPT efficiency:

$$\eta_t = \eta_{CONV} \times \eta_{MPPT} \quad (3)$$

where

η_t is the total energy conversion efficiency.

Note 1 to entry: Unit: dimensionless, usually expressed as a percentage, %.

3.20 weighted static energy conversion efficiency

η_s

efficiency calculated by using a ratio of irradiance and the results of static performance evaluation:

$$\eta_s = F_1 \eta_{t1} + F_2 \eta_{t2} + \dots + F_n \eta_{tn} \quad (4)$$

where

$\eta_{t1}, \eta_{t2}, \dots, \eta_{tn}$ are the total energy conversion efficiency values at rated power values of IEC 61683 defined;

F_1, F_2, \dots, F_n are the weighting factors of each power level that are defined from the distribution rate of the static state data at the location where the PV system is installed.

Note 1 to entry: Unit: dimensionless, usually expressed as a percentage, %.

**3.21
weighted dynamic energy conversion efficiency**

η_d
efficiency calculated by using a rate of change of irradiance and the results of dynamic performance evaluation:

$$\eta_d = J_1\eta_{t1d} + J_2\eta_{t2d} + \dots + J_n\eta_{tnd} \tag{5}$$

where

$\eta_{t1d}, \eta_{t2d}, \dots, \eta_{tnd}$ are the total energy conversion efficiency values at rate of change of irradiance (slope) values of IEC 62891 defined;

J_1, J_2, \dots, J_n are the weighted factors of each rate of change of irradiance that are defined from the distribution rates of the dynamic state data at the location where the PV system is installed.

Note 1 to entry: Unit: dimensionless, usually expressed as a percentage, %.

**3.22
weighted energy conversion efficiency**

η_E
efficiency calculated by using the sum of two products, static energy conversion efficiency and dynamic energy conversion efficiency:

$$\eta_E = \alpha\eta_s + \beta\eta_d \tag{6}$$

where

α, β are the appearance rates of static state data points and dynamic state data points.

Note 1 to entry: Unit: dimensionless, usually expressed as a percentage, %.

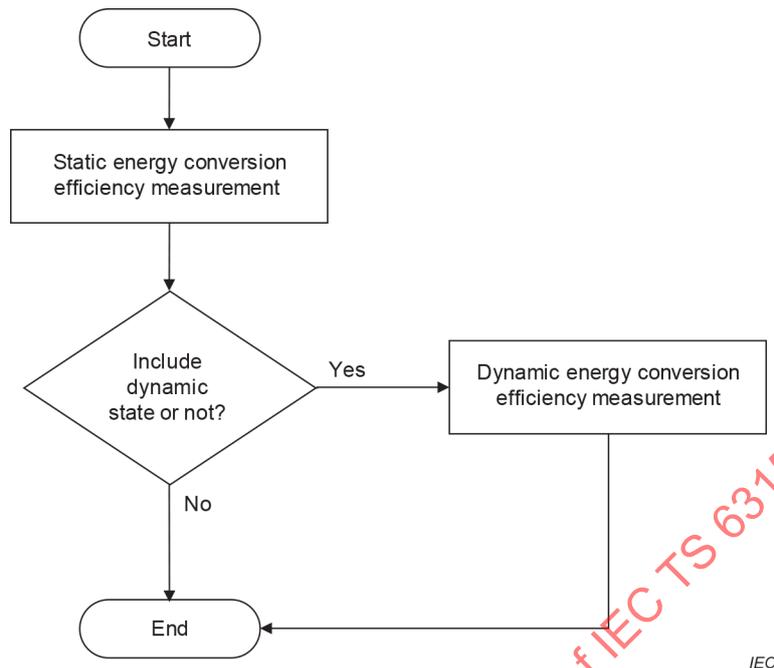
4 Workflow of energy conversion efficiency evaluation method

4.1 General

Clause 4 describes the workflow for the energy conversion efficiency evaluation method. This method consists of two parts. Part one (4.2) addresses the conversion efficiency measurements according to the procedures in IEC 61683 and IEC 62891. Part two (4.3) addresses the subsequent energy conversion efficiency calculations provided by this document using test data and solar load profiles.

Both steps have the option for evaluating the impact of dynamic energy conversion efficiency. For projects where there are not significant dynamic irradiance fluctuations, standard solar profiles can be used without including the dynamic energy efficiency measurement or calculation.

4.2 Flow of energy conversion efficiency evaluation test



IEC

Figure 1 – Flowchart of energy conversion efficiency evaluation test

Figure 1 shows the flow of the energy conversion efficiency evaluation for power conversion equipment. First, the static energy conversion efficiency should be measured with the rated input and output voltages based on the description of IEC 61683 (see Annex B). Then, if necessary, the dynamic energy conversion efficiency should be measured for meteorological or other conditions; the necessity should be determined by agreement between users and suppliers. The dynamic energy conversion efficiency method should be based on IEC 62891 (see Annex C).

4.3 Flow of energy conversion efficiency calculation

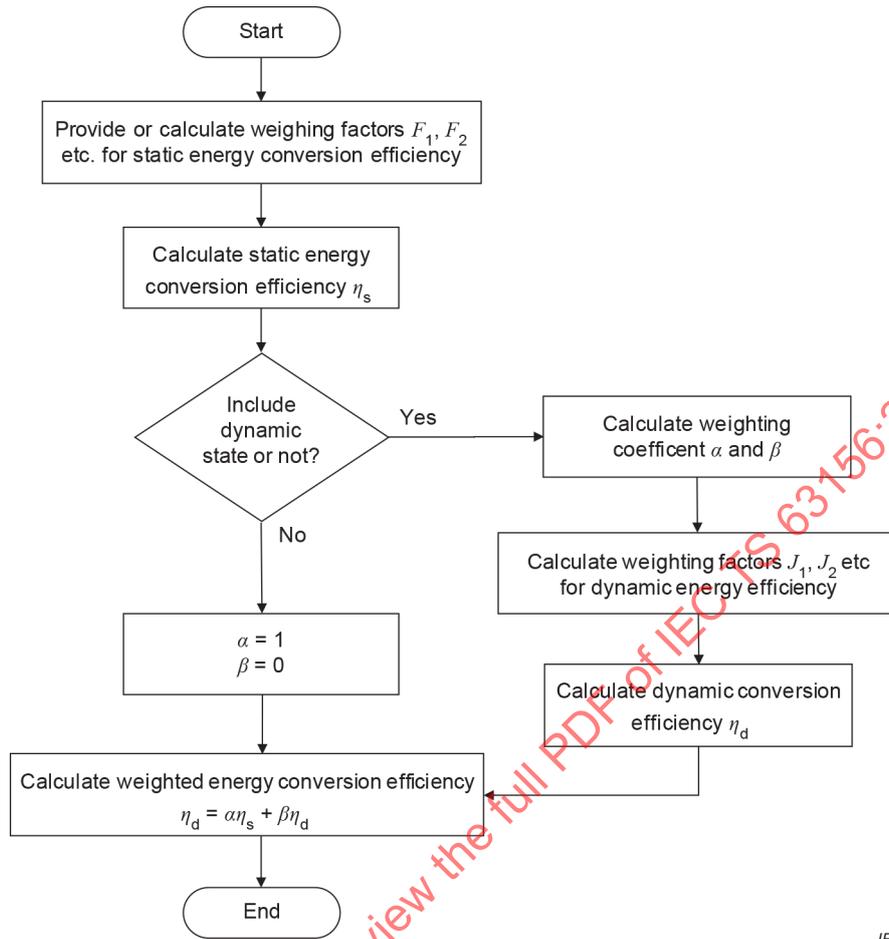


Figure 2 – Flowchart of energy conversion efficiency calculation

The flow of calculating the energy conversion efficiency is shown in Figure 2. If the dynamic energy conversion efficiency is measured, weighting coefficients for the static state and dynamic state are determined as α and β , respectively. See Annex A for a practical example of determining the weighting coefficients. If it is judged that the dynamic energy conversion efficiency measurement is unnecessary, the static energy conversion efficiency, η_s , is calculated using weighting factors for the static energy conversion efficiency, F_1, F_2 , etc. (see Annex A). η_s is equivalent to the weighted energy conversion efficiency, η_E . If it is judged that the dynamic energy conversion efficiency measurement is necessary, the weighting factors, F_1, F_2 , etc., are determined based on the meteorological conditions, installation environment and other conditions after calculating α and β (see Annex A). Then, the static energy conversion efficiency is calculated. Next, the weighting factors for dynamic energy conversion efficiency, J_1, J_2 , etc., are calculated (see Annex A). After that, the dynamic energy conversion efficiency, η_d , is determined. Finally, the weighted energy conversion efficiency, η_E , is calculated using η_s, η_d, α and β determined in the previous steps based on Formula (6).

5 Energy efficiency measurement conditions

5.1 Energy efficiency test circuit

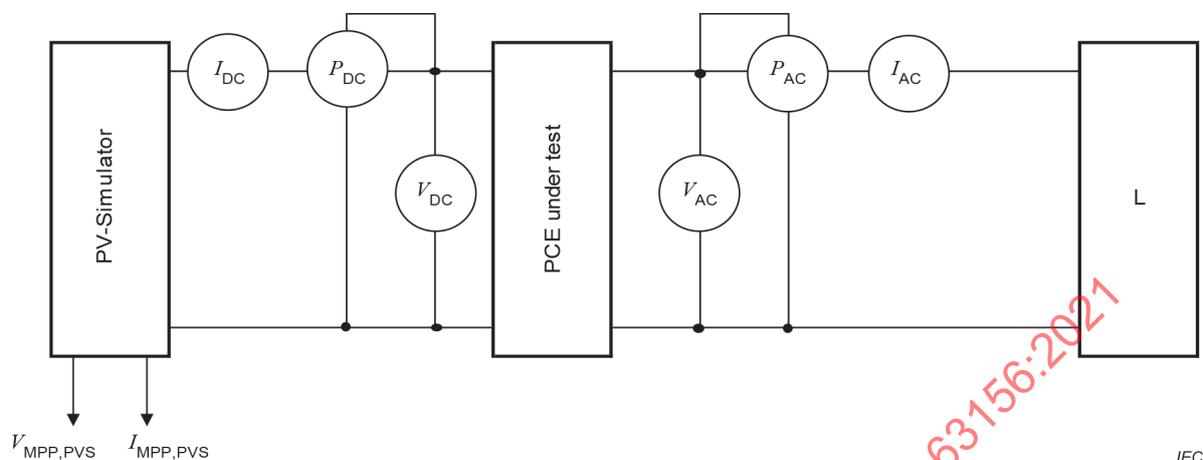


Figure 3a – Stand-alone type

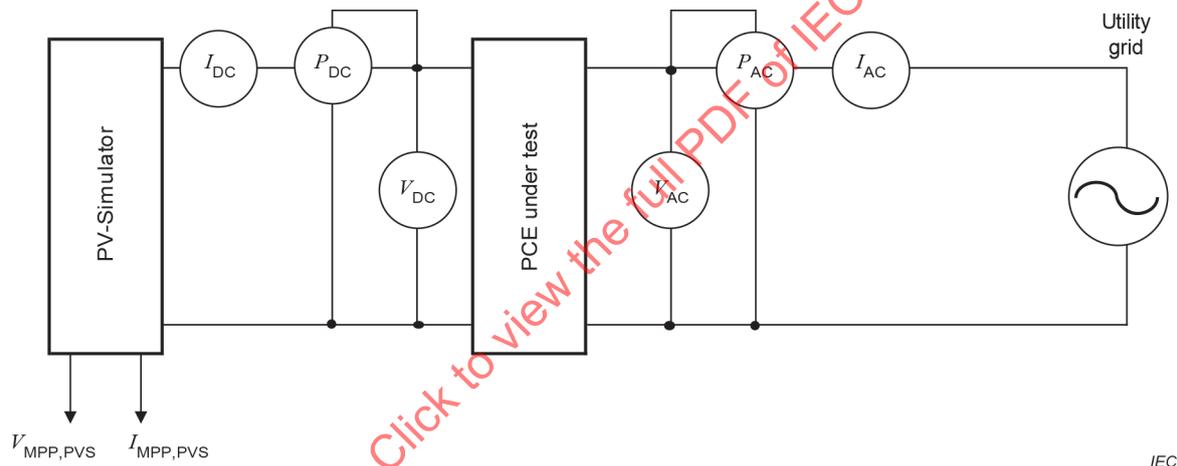


Figure 3b – Grid-connected type

Key

PCE	power conversion equipment	$I_{AC/DC}$	AC ammeter
I_{DC}	DC ammeter	V_{AC}	AC voltmeter
V_{DC}	DC voltmeter	P_{AC}	AC wattmeter
P_{DC}	DC wattmeter	L	load

Figure 3 – Power conversion equipment test circuits

Figure 3 shows recommended test circuits for power conversion equipment, which are basically the same as the test circuits described in IEC 61683. The test circuits in Figure 3a and 3b are applied to stand-alone and grid-connected power conversion equipment, respectively. The PV simulator, which is a DC power supply for the tests, shall meet the requirements described in IEC 62891.

$V_{MPP,PVS}$ and $I_{MPP,PVS}$ are provided by the PV simulator. MPPT efficiency, η_{MPPT} , is calculated using Formula (1). P_{DC} is integrated over period T_M , and may be calculated from the product of DC ammeter I_{DC} and DC voltmeter V_{DC} .

Energy conversion efficiency, η_{CONV} , is calculated using Formula (2). P_{AC} is integrated over the period T_M .

5.2 Test conditions

Test conditions are described in IEC 61683 and IEC 62891.

6 Static energy conversion efficiency evaluation

The evaluation of static energy conversion efficiency should follow IEC 61683. After the test, the static energy conversion efficiency η_s is calculated based on the flow shown in Figure 2 and Formula (4). See Annex B.

7 Dynamic energy conversion efficiency evaluation

The evaluation of dynamic energy conversion efficiency should follow the procedure described in Annex C with the rated input voltage of the power conversion equipment and the rated output voltage to the load or grid side. After the test, the dynamic energy conversion efficiency η_d is calculated based on the flow shown in Figure 2 and Formula (5). Dynamic energy conversion efficiency can be evaluated using the procedure described in IEC 62891.

8 Weighted energy conversion efficiency calculation

Finally, weighted energy conversion efficiency η_E is calculated using the static energy conversion efficiency η_s (from Clause 6), the dynamic energy conversion efficiency η_d (from Clause 7), and the weighting coefficients α and β (calculated using Formulas (A.3) and (A.4) in Annex A, as an example) based on Formula (6). Table 1 shows an example of the table for recording the weighted energy conversion efficiency. See Annex D.

Table 1 – Weighted energy conversion efficiency

	η_s	η_d	α	β	η_E
Equipment under test					

Annex A (informative)

Rate of change of irradiance

A.1 Analysis of irradiance profile

Conduct irradiance change analysis. First, obtain the irradiance data (G_1) of the location where the PV system is installed. The data sampling rate should be set to less than 1 s to allow for the dynamic performance test. Next, calculate the rate of change of irradiance (R_1, R_2 , etc.) of in-plane irradiance (G_{11}, G_{12} , etc.) at each time (t_1, t_2 , etc.). Classify into two classes, static state and dynamic state, by the rate of change of irradiance, and calculate the appearance rates (weighting coefficient) from the distribution of the two classes.

$$\frac{|G_{12} - G_{11}|}{t_2 - t_1} = \frac{\Delta G_{11}}{\Delta t_1} = R_1, \quad \frac{|G_{13} - G_{12}|}{t_3 - t_2} = \frac{\Delta G_{12}}{\Delta t_2} = R_2, \text{ etc.} \quad (\text{A.1})$$

where

R_1, R_2 , etc. are the rate of change of irradiance at time t_1, t_2 , etc., in $\text{W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$;

G_{11}, G_{12} , etc. are the in-plane irradiance at time t_1, t_2 , etc., in $\text{W}\cdot\text{m}^{-2}$;

$\Delta t_1, \Delta t_2$, etc. are the time interval, in s.

$$R_1 > C_1, R_2 > C_1, \text{ etc.} \quad (\text{A.2})$$

where

C_1 is the threshold value that separates the static state and the dynamic state, in $\text{W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. C_1 is determined based on clear day as the static state.

The data points that satisfy Formula (A.2), i.e., the data R_1, R_2 , etc. that exceed C_1 , are defined as dynamic state data, while the data points that are less than C_1 are defined as static state data.

The appearance rates α and β are defined as follows:

$$\alpha = \frac{N_1}{N_1 + N_2} \quad (\text{A.3})$$

$$\beta = \frac{N_2}{N_1 + N_2} \quad (\text{A.4})$$

where

N_1 is the number of static state data points;

N_2 is the number of dynamic state data points.

It is recommended to select the irradiance pattern that represents the actual irradiance change at the location. Calculate the static energy conversion efficiency η_s and the dynamic energy

conversion efficiency η_d using the results of each total energy conversion efficiency and the results of the appearance rates as follows:

$$\eta_s = F_1\eta_{t5} + F_2\eta_{t10} + F_3\eta_{t20} + F_4\eta_{t30} + F_5\eta_{t50} + F_6\eta_{t75} + F_7\eta_{t100} \quad (\text{A.5})$$

where

$\eta_{t5}, \eta_{t10}, \eta_{t20}, \text{ etc.},$ are the total energy conversion efficiency values at rated power values of 5 %, 10 %, 20 %, etc., measured during the static energy conversion efficiency evaluation;

$F_1, F_2, F_3, \text{ etc.},$ are the weighting factors of each power level that are defined from the distribution rate of the static state data at the location where the PV system is installed.

$$\eta_d = J_1\eta_{t10d} + J_2\eta_{t14d} + J_3\eta_{t20d} + J_4\eta_{t30d} + J_5\eta_{t50d} + J_6\eta_{t100d} \quad (\text{A.6})$$

where

$\eta_{t10d}, \eta_{t14d}, \eta_{t20d}, \text{ etc.},$ are the total energy conversion efficiency values at rate of change of irradiance, e.g. $10 \text{ W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}, 14 \text{ W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}, 20 \text{ W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}, \text{ etc.},$ measured during the dynamic energy conversion efficiency evaluation;

$J_1, J_2, J_3, \text{ etc.},$ are the weighted factors of each rate of change of irradiance that are defined from the distribution of rates at the location where the PV system is installed.

The weighted energy conversion efficiency is derived from the calculation results of Formula (6).

Figure A.1 shows an example of an irradiance profile, measured with a photodiode-based pyranometer. The rate of change of irradiance is explained using the example of a one-day irradiance profile. Firstly, obtain the irradiance profile to be analyzed. This example uses irradiance data recorded every second. From Formula (A.2), $C_1 = 2 \text{ W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ is used for this example analysis. Then, calculate of the rate of change of irradiance $R_1, R_2, \text{ etc.},$ for each data point of the irradiance profile, and classify the data as static or dynamic state. In this case, most of the data points are classified as dynamic state. The remaining points, i.e. the static state data points, are shown in Figure A.2. Table A.1 shows the weighted factors for the static state as $F_{n=1 \text{ to } 7}$.

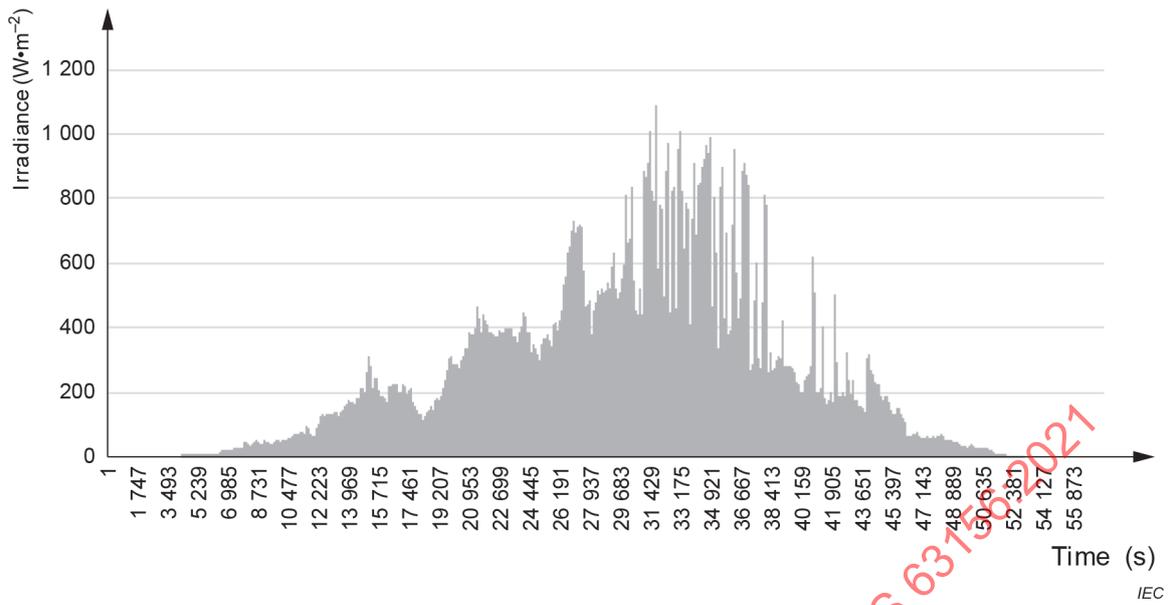


Figure A.1 – Example of irradiance profile

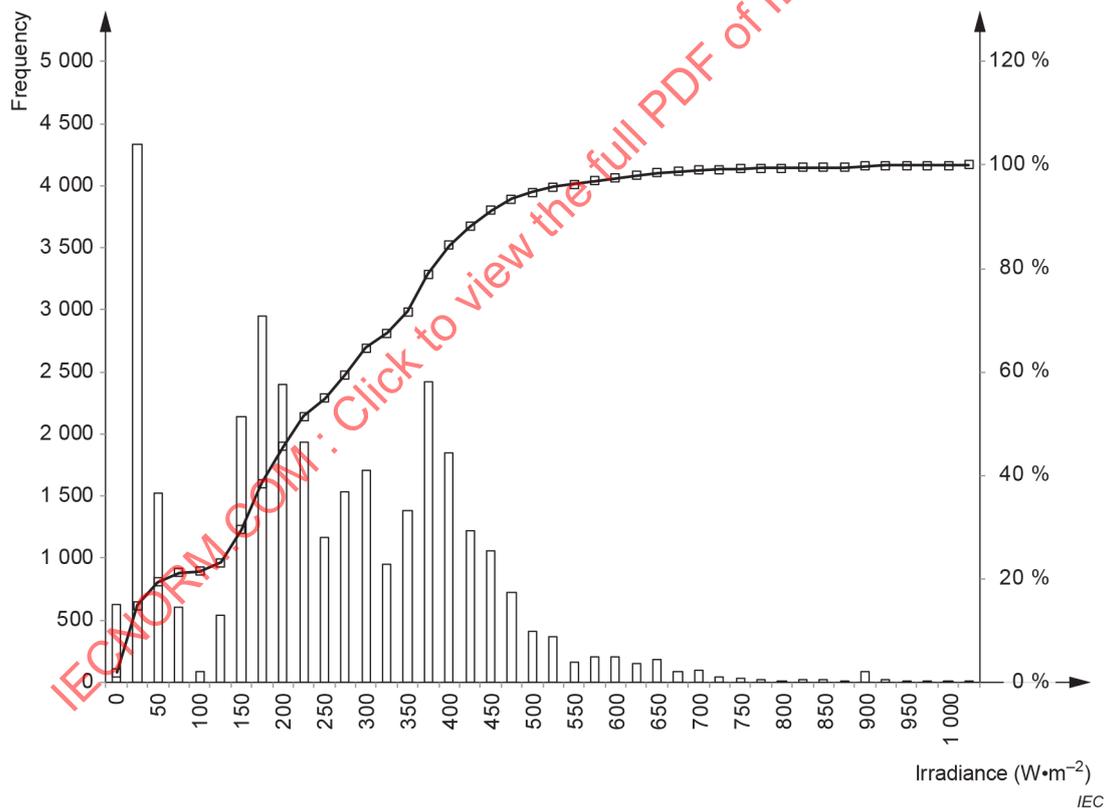


Figure A.2 – Histogram of the irradiance in Figure A.1 ($< 2 \text{ W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)

Table A.1 – Weighted factor ratios for $F_{n=1}$ to 7

Weighted factor for static state	F_1	F_2	F_3	F_4	F_5	F_6	F_7
Power level (%)	-	0 to 10	10 to 20	20 to 30	30 to 50	50 to 75	75 to 100
Number of data points	-	7 085	5 715	7 031	11 304	1 916	270
Rate (%)	-	21,3	17,2	21,1	33,9	5,7	0,8

A.2 Rate of change of irradiance

Next, create a histogram of the absolute rate of change of irradiance using the data points classified as dynamic state data points in Clause A.1. Figure A.3 shows the histogram of rate of change of irradiance more than $2 \text{ W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. The weighted factors for the dynamic state are calculated as shown in Table A.2 from the distribution rates in the histogram. In this case, J_2 is neglected.

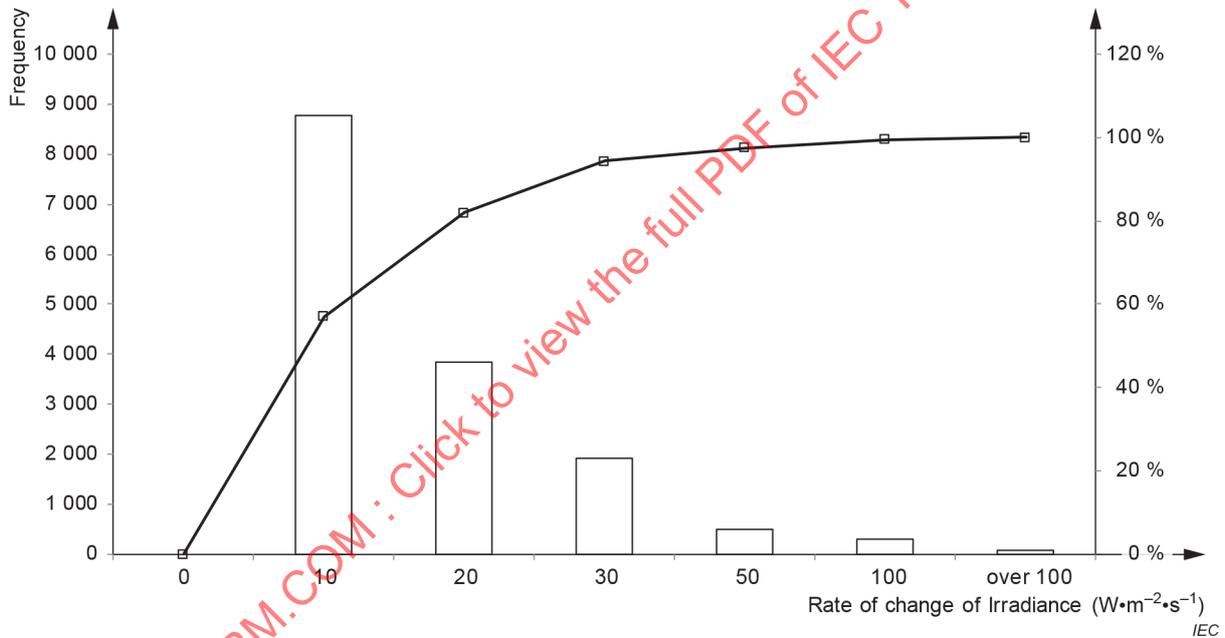


Figure A.3 – Histogram of rate of change of irradiance ($>2 \text{ W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)

Table A.2 – Weighted factor ratios for J_1, J_2 , etc.

Weighted factor for dynamic state	J_1	J_2	J_3	J_4	J_5	J_6
Range of change of Irradiance ($\text{W}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)	2 to 10	-	10 to 20	20 to 30	30 to 50	over 50
Rate of change (%)	57,1	-	24,9	12,4	3,2	2,5

Annex B (informative)

Static energy conversion efficiency test sequence

Set the rated input voltage, the rated output voltage, and the frequency to the grid side of the power conversion equipment. Measure the total energy conversion efficiency at each power level of 100 %, 75 %, 50 %, etc., in Table B.1. The efficiencies η_{t100} , η_{t75} , η_{t50} , etc., recorded in the table are obtained from the measured results, Formula (3) and the method described in Clause A.1. The static energy conversion efficiency η_s is calculated using the total energy conversion efficiencies η_{t100} , η_{t75} , η_{t50} , etc. and the weighted factors F_1 , F_2 , F_3 , etc. from the irradiance histogram by using Formula (A.5).

Table B.1 – Static energy efficiency

	DC input power level ($P_{MPP,PVS}$) from PV simulator						
	5 % η_{t5}	10 % η_{t10}	20 % η_{t20}	30 % η_{t30}	50 % η_{t50}	75 % η_{t75}	100 % η_{t100}
$V_{DC,r} =$							
$V_{AC,r} =$							

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Annex C (informative)

Dynamic energy conversion efficiency test sequence

Set the rated input voltage, the rated output voltage, and the frequency at the grid side of the power conversion equipment. Change the power level from 30 % to 100 % to simulate the irradiance change using the DC input power level against the rated input power from the PV simulator. Measure the total energy conversion efficiencies η_{t10d} , η_{t14d} , η_{t20d} , etc., when changing the rate of change of irradiance. Table C.2 shows an example of the table for recording the dynamic energy efficiency. The recorded efficiencies η_{t10d} , η_{t14d} , η_{t20d} , etc., are calculated using the measured result Formula (3) and the method described in Clause A.1. The dynamic energy conversion efficiency η_d is calculated using the total energy conversion efficiencies η_{t10d} , η_{t14d} , η_{t20d} , etc., the weighted factors for the dynamic states J_1 , J_2 , J_3 , etc. and Formula (A.6). 100 % in Table C.1 corresponds to $1\,000\text{ W}\cdot\text{m}^{-2}$ at $25\text{ }^\circ\text{C}$. Each parameter in Figure C.1 is set using the values given in Table C.1. The description in this annex is quoted from IEC 62891 and is an example of dynamic energy conversion evaluation.

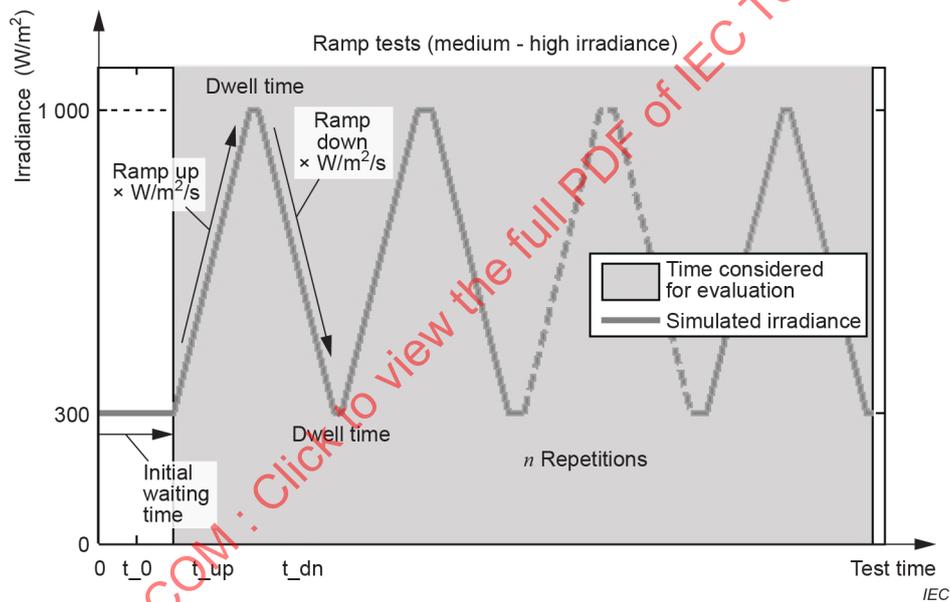


Figure C.1 – Test sequence for fluctuations between medium and high irradiation intensities