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Celovita učinkovitost fotonapetostnih razsmernikov

Overall efficiency of photovoltaic inverters

Gesamtwirkungsgrad von Photovoltaik-Wechselrichtern

Rendement global des onduleurs photovoltaïques

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English version

Overall efficiency of grid connected photovoltaic inverters

Efficacité globale des onduleurs photovoltaïques raccordés au réseau

Gesamtwirkungsgrad von Photovoltaik-Wechselrichtern

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CENELEC

European Committee for Electrotechnical Standardization
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Foreword

This European Standard was prepared by the Technical Committee CENELEC TC 82, Solar photovoltaic energy systems. It was submitted to the Unique Acceptance Procedure and approved by CENELEC on 2010-04-01.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-04-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2013-04-01

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1 Scope

This European Standard provides a procedure for the measurement of the efficiency of the maximum power point tracking (MPPT) of inverters, which are used in grid-connected photovoltaic systems. In that case the inverter energizes a low voltage grid with rated AC voltage and rated frequency. Both the static and dynamic MPPT efficiency is considered.

Based on the static MPPT efficiency and conversion efficiency the overall inverter efficiency is calculated. The dynamic MPPT efficiency is indicated separately.

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.

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

EN 50160, Voltage characteristics of electricity supplied by public distribution networks

EN 50524, *Data sheet and name plate for photovoltaic inverters*

CLC/TS 61836, *Solar photovoltaic energy systems - Terms, definitions and symbols* (IEC/TS 61836:2007)

3 Terms and definitions

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

3.1 Inverter input (PV generator)

3.1.1
maximum input voltage (U_{DCmax})
allowed maximum voltage at the inverter input

NOTE Exceeding of U_{DCmax} may destroy the equipment under test.

3.1.2
minimum input voltage (U_{DCmin})
minimum input voltage for the inverter to energize the utility grid, independent of mode of operation

3.1.3
rated input voltage ($U_{DC,r}$)
input voltage specified by the manufacturer, to which other data sheet information refers

NOTE If this value is not specified by the manufacturer, $V_{dc,r} = (V_{mppmax} + V_{mppmin})/2$ shall be used.

3.1.4
maximum MPP voltage (U_{MPPmax})
maximum voltage at which the inverter can convert its rated power under MPPT conditions

NOTE If the specified value of the manufacturer for U_{MPPmax} is higher than 0,8 × U_{DCmax}, the measurement must be performed with U_{MPPmax} = 0,8 × U_{DCmax}.

3.1.5
minimum MPP voltage (U_{MPPmin})
minimum voltage at which the inverter can convert its rated power under MPPT conditions

NOTE The actual minimum MPP voltage may depend on the grid voltage level.

3.1.6
rated input power ($P_{DC,r}$)
rated input power of the inverter, which can be converted under continuous operating conditions

NOTE If this value is not specified by the manufacturer, it can be defined as $P_{DC,r} = P_{AC,r} / \eta_{conv,r}$, in which $\eta_{conv,r}$ is the conversion efficiency at rated DC voltage.

3.1.7
maximum input current ($I_{DC,max}$)
maximum input current of the inverter under continuous operating conditions

NOTE At inverters with several independent inputs, this value may depend on the chosen input configuration.

3.2 Inverter output (grid)

3.2.1
rated grid voltage ($U_{AC,r}$)
utility grid voltage to which other data sheet information refers

3.2.2
rated power ($P_{AC,r}$)
active power the inverter can deliver in continuous operation

3.3 Measured quantities

3.3.1
PV simulator MPP-Power ($P_{MPP, PVS}$)
MPP power provided by the PV simulator

3.3.2
input power (P_{DC})
measured input power of the device under test

3.3.3
PV simulator MPP voltage ($U_{MPP, PVS}$)
MPP voltage provided by the PV simulator

3.3.4
input voltage (U_{DC})
measured input voltage of the device under test

3.3.5
PV simulator MPP current ($I_{MPP, PVS}$)
MPP current provided by the PV simulator

3.3.6
input current (I_{DC})
measured input current of the device under test

3.3.7
output power (P_{AC})
measured AC output power of the device under test

3.3.8
output voltage (U_{AC})
measured AC voltage

3.3.9
output current (I_{AC})
measured AC output current of the device under test

3.4 Calculated quantities

3.4.1
MPPT efficiency, energetic (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 in the maximum power point (MPP):

$$\eta_{MPPT} = \frac{\int_0^{T_M} p_{DC}(t) \cdot dt}{\int_0^{T_M} p_{MPP}(t) \cdot dt} \tag{1}$$

where

$p_{DC}(t)$ instantaneous value of the power drawn by the device under test;

$p_{MPP}(t)$ instantaneous value of the MPP power provided theoretically by the PV simulator

3.4.2
conversion efficiency, energetic (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 accepted by the device under test at the DC terminal:

$$\eta_{conv} = \frac{\int_0^{T_M} p_{AC}(t) \cdot dt}{\int_0^{T_M} p_{DC}(t) \cdot dt} \tag{2}$$

where

$p_{AC}(t)$ instantaneous value of the delivered power at the AC terminal of the device under test;

$p_{DC}(t)$ instantaneous value of the accepted power at the DC terminal of the device under test

3.4.3
overall (total) efficiency, energetic (η_t)
ratio of the energy delivered by the device under test at the AC terminals within a defined measuring period T_M to the energy provided theoretically by the PV simulator:

$$\eta_t = \frac{\int_0^{T_M} p_{AC}(t) \cdot dt}{\int_0^{T_M} p_{MPP}(t) \cdot dt} \text{ respectively } \eta_t = \eta_{conv} \cdot \eta_{MPPT} \tag{3}$$

3.5 Other definitions

3.5.1
photovoltaic array simulator
current source emulating the static and dynamic behaviour of a PV array, in particular the current-voltage characteristic (cf. IEC/TS 61836). The requirements are outlined in Clause A.1

4 MPPT and conversion efficiencies

4.1 General description

The MPPT efficiency describes the accuracy of an inverter to set the maximum power point on the characteristic curve of a PV generator. The MPPT efficiency is divided into the static and dynamic case. Both the static as well as the dynamic MPPT efficiencies are determined from the sampled instantaneous values of voltage and current at the input of the inverter. It indicates which amount of the theoretically usable PV generator power is actually used by the inverter.

a) Static MPPT efficiency

The static MPPT efficiency is determined by means of measurement as follows:

$$\eta_{MPPTstat} = \frac{1}{P_{MPP,PVS} \cdot T_M} \sum_i U_{DC,i} \cdot I_{DC,i} \cdot \Delta T \tag{4}$$

where

$U_{DC,i}$ sampled value of the inverter's input voltage;

$I_{DC,i}$ sampled value of the inverter's input current;

T_M overall measuring period;

ΔT period between two subsequent sample values.

The static MPPT efficiency describes the accuracy of an inverter to regulate on the maximum power point on a given static characteristic curve of a PV generator.

NOTE $U_{DC,i}$ and $I_{DC,i}$ must be sampled at the same time.

b) Dynamic MPPT efficiency

Variations of the irradiation intensity and the resulting transition of the inverter to the new operation point are not considered with the static MPPT efficiency. For the evaluation of this transient characteristic the dynamic MPPT efficiency is specified. The dynamic MPPT efficiency is defined as:

$$\eta_{MPPTdyn} = \frac{1}{\sum_j P_{MPP,PVS,j} \cdot \Delta T_j} \sum_i U_{DC,i} \cdot I_{DC,i} \cdot \Delta T_i \tag{5}$$

where

ΔT_j period in which the power $P_{MPP,PVS,j}$ is provided;

ΔT_i period in which the power $U_{DC,i}$ and $I_{DC,i}$ are sampled.

4.2 Test set-up

The generic test set-up for single phase grid connected inverters is depicted in Figure 1. The diagram can also be considered as a single phase representation of a test-circuit for multi phase inverters.

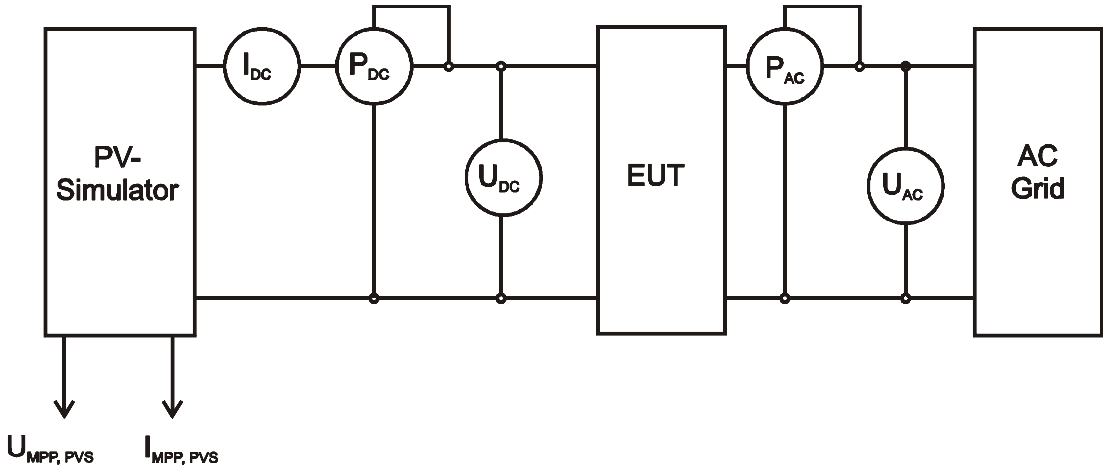

Figure 1 – Exemplary test set-up for MPPT efficiency measurements

Key

EUT Equipment under test (inverter);

I_{DC} DC current meter;

U_{DC} DC voltage meter;

P_{DC} DC power meter;

U_{AC} AC voltage meter;

P_{AC} AC power meter.

The DC source connected to the PV input of the inverter shall be a PV simulator in accordance to the specifications in Clause A.1.

The AC supply of the inverter must be in accordance to the specifications in Clause A.2.

NOTE The dc and ac voltages must be measured as close as possible to the inverter terminals.

4.3 Static MPPT efficiency

4.3.1 Test conditions for the static MPPT efficiency

The measurement of the static MPPT efficiency must be performed with test specifications as defined in Table 1.

For test devices with several independent input terminals, the measurements must be performed for all input configurations as intended by the manufacturer. Unless otherwise provided by the manufacturer, the total power must be split equally on the individual input terminals.

NOTE The measurement of the static MPPT should be performed preferably in combination with the conversion efficiency measurement (see 4.5).

Table 1 – Test specifications for the static MPPT efficiency

MPP voltage of the simulated I/U characteristic of the PV generator	Simulated I/U characteristic (see Annex C)	MPP power of the simulated I/U characteristic normalised to rated DC power [d], $P_{MPP,PVS}/P_{DC,r}$							
		0,05	0,10	0,20	0,25	0,30	0,50	0,75	1,00
U_{MPPmax} ($0{,}8 \cdot U_{DCmax}$ [a,c])	c-Si								
$U_{DC,r}$	c-Si								
U_{MPPmin}	c-Si								
U_{MPPmax} ($0{,}7 \cdot U_{DCmax}$ [a,c])	TF [b]								
$U_{DC,r}$	TF [b]								
U_{MPPmin}	TF [b]								

[a] The value whichever is lower shall be used. The specified MPP voltages ensure that the correct MPPT operation is not affected by reaching voltage limits.

[b] For devices under test, that are not intended for the operation with thin-film technologies, these measuring points can be omitted.

[c] For other cell technologies the value $U_{MPPmax} = n \cdot U_{DCmax}$ must be set accordingly.

[d] In order to specify the static MPPT efficiency in terms of normalised rated AC power, the procedure in Annex E shall be used

The measurement shall be performed at nominal grid voltage $U_{AC,r}$ in order to avoid any impact of the grid voltage level on the measurement results. Deviations must be documented in the measurement report.

The measurements have to be made at the same reference ambient conditions as conversion efficiency measurements according to EN 61683.

4.3.2 Measurement procedure

For each of the above specified test conditions a corresponding I/U characteristic has to be defined which must be emulated by means of the PV simulator.

NOTE 1 The requirements on the accuracy of the defined characteristic are outlined in Annex C.

After commissioning the device under test the stabilization of the MPP tracking must be awaited firstly.

NOTE 2 According to the multitude of various MPPT methods and its parameters a certain waiting period is not defined in this standard. The stabilization time depends on the individual characteristic of the device under test and must be set accordingly in each case. It must be documented in the test report. If a stabilisation of the MPPT can't be observed, due to the behaviour of the device under test, a latency of at least 5 min is defined.

After the stabilization of the MPP tracking the following parameters have to be logged for a period of 10 min:

– P_{MPPPVS} MPP power provided by the PV simulator;

– P_{DC} measured input power of the device under test;

– U_{MPPPVS} MPP voltage provided by the PV simulator;

– U_{DC} measured input voltage of the device under test;