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TECHNICAL SPECIFICATION

colour inside

Simulators used for testing of photovoltaic power conversion equipment – Recommendations – Part 2: DC power simulators

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SIMULATORS USED FOR TESTING OF PHOTOVOLTAIC POWER CONVERSION EQUIPMENT – RECOMMENDATIONS –

Part 2: DC power simulators

FOREWORD

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

Draft	Report on voting
82/1954/DTS	82/1999/RVDTS

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 Technical Specification 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.

A list of all parts in the IEC TS 63106 series, published under the general title *Simulators used for testing of photovoltaic power conversion equipment – Recommendations* , can be found on the IEC web site.

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- withdrawn,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 objective of this document is to establish terminology, create a framework for, and provide guidance regarding the electrical performance of DC power simulators used to test photovoltaic (PV) power conversion equipment (PCE) for compliance with grid interconnection or PV performance standards.

Along with IEC TS 63106-1, it provides guidance for the selection or development of power simulators used within a test and evaluation system for PV PCEs.

Testing laboratories are responsible for selecting the appropriate test items and procedures as well as defining the required performance for adequate evaluation of utility interactive PV PCEs, considering utility power requirements, local codes and regulations.

It is intended for this document to be used in conjunction with parallel PCE standards developed for specific performance or grid-interaction requirements.

SIMULATORS USED FOR TESTING OF PHOTOVOLTAIC POWER CONVERSION EQUIPMENT – RECOMMENDATIONS –

Part 2: DC power simulators

1 Scope

The purpose of this part of IEC TS 63106 is to provide recommendations for Low Voltage (LV) DC power simulators used for testing photovoltaic (PV) power conversion equipment (PCE) to utility interconnection or PV performance standards.

NOTE Low Voltage refers to DC voltage 1 500 V and less.

In this document, the term "DC power simulator" refers to any source that is used during testing to provide DC power to the Equipment Under Test (EUT). That includes, but is not limited to, PV array simulators designed to simulate the DC output I-V curve of a photovoltaic array operating in real-world conditions.

This document primarily addresses DC power simulators used for testing of grid-interactive PCE, also referred to as grid-connected power converters (GCPCs). It also addresses some uses of DC power simulators for testing stand-alone and multi-mode PCEs.

There are many types of tests that can be conducted by utilizing a DC power simulator. Certain tests require the use of a PV array or PV array simulator, such as measurements of the PCE's PV input static and dynamic characteristics related to maximum power point tracking, while other tests may be appropriate to conduct with a static DC power supply. Test requirements and procedures are specified in IEC standards and local utility grid requirements, selected by the system integrator, PCE manufacturer, network operator, utility, or third-party inspector.

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 62116, *Utility-interconnected photovoltaic inverters – Test procedure of islanding prevention measures*

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

IEC TS 62910:2020, *Utility-interconnected photovoltaic inverters – Test procedure for under voltage ride-through measurements*

IEC TS 63106-1:2020, *Simulators used for testing of photovoltaic power conversion equipment – Recommendations – Part 1: AC power simulators*

EN 50530, *Overall 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, and 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
DC power simulator
system or device able to source and/or absorb DC power, for use in testing of PCE

Note 1 to entry: In this document, DC power simulator is the general term including PV array, conventional DC power supply or PV array simulator.

3.2
PV array simulator
type of DC power simulator that implements the key characteristics of the I-V curve of real photovoltaic module types, having a maximum power point, operating voltage, and available current that vary with load and irradiance

3.3
power conversion equipment
PCE
electrical device converting one kind of electrical power from a voltage or current source into another kind of electrical power with respect to voltage, current and frequency

[SOURCE: IEC 62109-1:2010, 3.66]

3.4
port
terminal or set of terminals where the PCE connects to conductors of an external power, control, or communications system

Note 1 to entry: See Figure 1 for examples of ports.

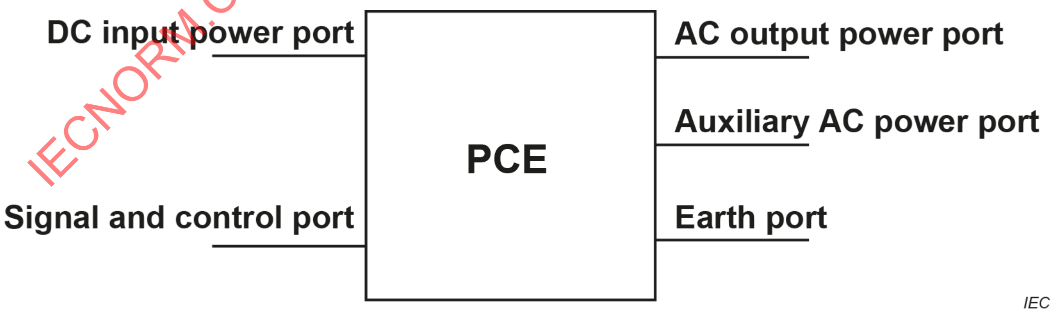

Figure 1 – Examples of ports

3.5
equipment under test
EUT
PCE that is tested by connecting and supplying DC and AC power to each port

3.6
AC output power port
port used to connect to a public low voltage AC mains power distribution network or other low voltage AC mains installation

3.7
DC input power port
port used to connect the PCE to the DC power simulator during testing, or a PV array or other DC source in the installation

3.8
type test
conformity test performed on one or more items representative of the production

[SOURCE: IEC 60050-151:2001, 151-16-16]

3.9
maximum power point
MPP
operational voltage and current point on the output characteristic of photovoltaic module or array that delivers the largest output power depending on solar irradiance and temperature

3.10
maximum power point tracking
MPPT
PCE control function to survey the maximum input DC power point on the characteristic of photovoltaic modules power generation

3.11
under voltage ride through
UVRT
PCE operational durability for the situation of low voltage supply by the AC power system

3.12
open circuit voltage
$V_{\mathbf{oc}}$
open circuit voltage that appears at the output terminal of photovoltaic module or array under solar irradiation

3.13
short circuit current
$I_{\mathbf{sc}}$
short circuit current that appears at the output terminal of photovoltaic module or array under solar irradiation

4 PCE types with respect to DC voltage levels

4.1 General

PV PCE may be connected to PV modules or arrays in a variety of ways.

The maximum limit of the operating DC voltage range of PV PCE takes into account the absolute maximum value of the open circuit voltage of the array under any condition (irradiance, temperature, etc.).

Therefore, an upper limit of 1 500 V for the DC voltage range of a PCE test system is sufficient.

4.2 Module level PCE

Module level PCE is connected to a single PV module with operating voltages typically in the DC voltage 65 V to 100 V range.

However, some DC to DC converters are used in series connection, so it may be necessary for the DC power simulator to be able to superimpose the system voltage (e.g. DC 1 000 V), with respect to earth, depending on the test purpose.

4.3 String level PCE

String level PCE is connected to series strings of PV modules, with operating and system voltages typically from DC voltage 600 V to 1 500 V maximum.

4.4 Central PCE

Central PCE is connected to a large number of series strings of PV modules in parallel, with operating and system voltages typically from DC voltage 600 V to 1 500 V maximum.

5 Test setup for utility interactive inverters

5.1 General

In order to realize valid and reproducible testing, the DC power source should be appropriate for the test being performed. This may mean utilizing an actual PV array, a conventional DC power supply, or a PV array simulator depending on the needs of the specific test under consideration.

In order to realize valid and reproducible testing, the AC power source should also be appropriate for the test being performed. Recommendations for AC power simulators are addressed in IEC TS 63106-1.

5.2 Test setup examples

Figure 2 illustrates basic configuration examples for the EUT test system. Here, EUT is the PV PCE under test. A DC power simulator is connected to the DC input power port. An AC power simulator is connected to the AC output power port, with other optional impedance and load equipment.

Figure 2 shows only the main power line connections to DC port, AC port in both sides. An earth line may be shared between DC side and AC side devices.

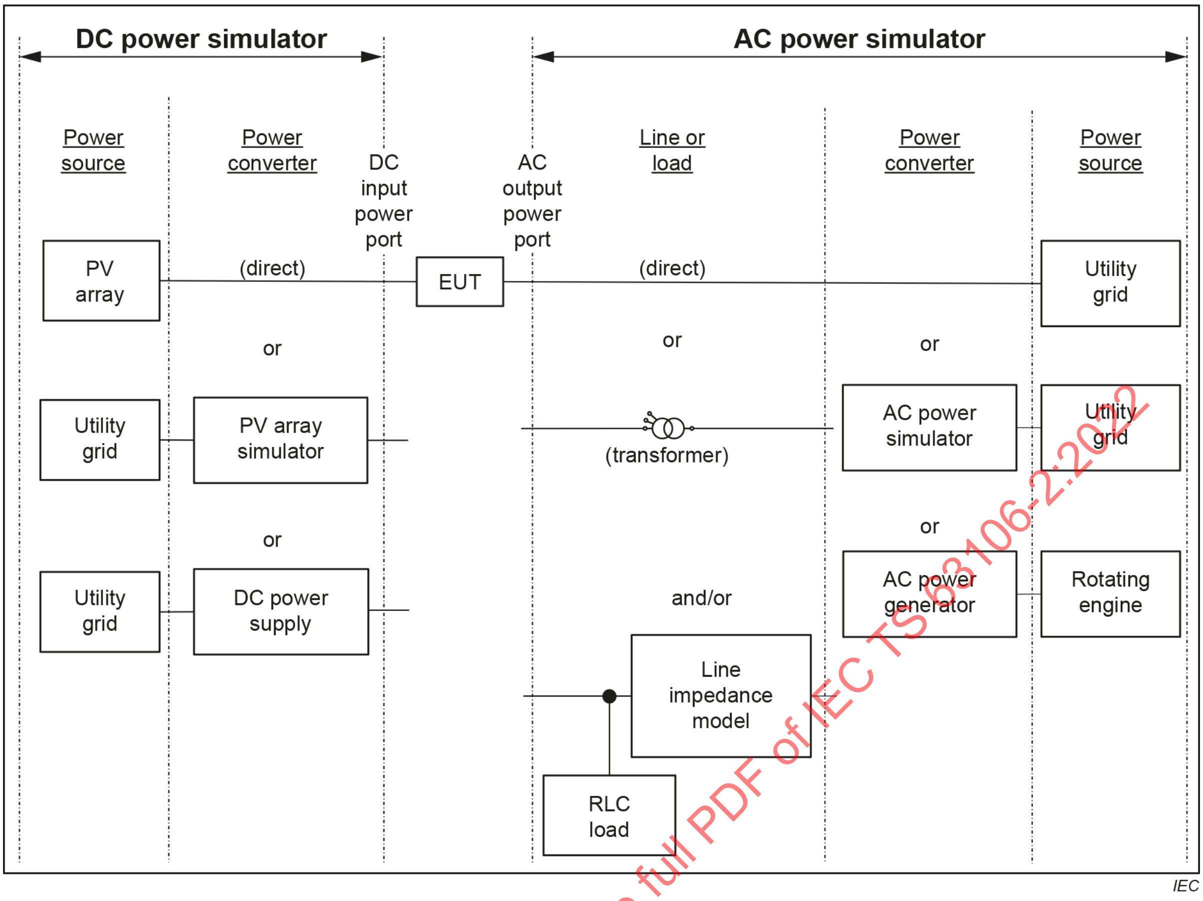

Figure 2 – Examples of fundamental setup of EUT test system

5.3 System configuration options

5.3.1 General

DC power simulators may consist of one or more of the following types of equipment. Other approaches are possible depending on the test(s) under consideration.

As different tests have different power simulator needs, it may be necessary or optimal for a facility to have more than one type of DC power simulator.

5.3.2 PV array

A PV array provides real-world irradiance variations, etc., which may be useful or necessary for some types of tests. However, irradiance conditions may make it impractical for tests that need stable, continuous and full capacity output power, so test feasibility and scheduling are subject to time and weather conditions.

For module level or very small array level PCE, an indoor array with artificial lighting may be a viable option.

In all cases where a real PV array is used, the response depends on the module technology (crystalline, thin film, etc.) and cannot be changed.

A PV array is also used as an option for an evaluation of output voltage/current characteristics of a PV array simulator or DC power supply, in case the performance of the PV array simulator or DC power supply has to be compared to a real PV array for the test combined with PCE.

5.3.3 PV array simulator

A PV array simulator is a power supply that has I-V curve characteristics resembling an actual PV module array.

The I-V curve can be based on information from PV module manufacturers or could be specified in the standards that the PCE is being tested to (e.g., IEC 62891 or EN 50530).

PV array simulators provide voltage, current and power with the characteristics of real PV modules but without dependence on time and weather conditions.

They can be configured to simulate different irradiance levels and module technologies (crystalline, thin film, etc.).

As some aspects of PCE functionality and performance may be critically dependent on, or influenced by, the I-V curve, use of an PV array simulator may be necessary or preferred for certain types of tests.

NOTE The I-V curve characteristics examples of crystalline and thin film PV modules used for the EUT testing are indicated in IEC 62891 and EN 50530.

5.3.4 DC power supply

A DC power supply is a general-purpose AC to DC power converter with no capability for simulating the I-V curve of a PV module. Such power supplies typically operate their output in constant voltage or constant current mode and offer stable control over DC voltage and the available current and power.

However, this square-shaped I-V curve represents a unity fill-factor, which does not occur in real PV arrays.

The extent to which a DC power supply will work for certain type tests depends on whether or not the test results rely on or can be affected by the I-V curve of the source. Also, the EUT's MPPT control software may not find a stable operating point when the source has a rectangular I-V curve.

The issue may be rectified by applying a series resistance between the DC power supply and the EUT, creating a roll-off curve and MPP that is easier for the EUT's control software to locate.

When applying a series resistance, the maximum DC voltage applied to EUT with zero-current output, should be known and should not exceed the maximum rated voltage of EUT.

However, when the EUT's power capacity is at MW-scale, the power consumption and heat dissipation due to series resistance may be prohibitively large.

6 General recommendations for DC power simulator

6.1 General

In this clause, general recommendations for DC power simulators are indicated.

The AC power input frequency and voltage requirements for DC power simulators are specified by the manufacturer considering the DC output voltage/current accuracy, including dynamic performance.

6.2 DC output voltage accuracy and ripple

The simulator output voltage accuracy should comply with the accuracy requirements of the standards in which the tests being performed are specified, and should be adequate to allow proper and repeatable testing.

This may require attention to accuracy under static conditions, across line and load variations, and possibly under load ramp or step change conditions.

DC output voltage ripple of DC power simulators should be taken into consideration if required to comply with standards in which the tests being performed are specified, or for proper and repeatable testing.

While a real PV array inherently creates ripple-free DC voltage for static operation point of V-I curve, the connected equipment such as inverters may create significant voltage ripple due to their topology and/or inherent current ripple. Correct testing may or may not require attention to voltage ripple. See also 6.3.1.4.

Standards specifying ripple limits for testing of PV equipment should consider this carefully to avoid unrealistic and onerous requirements.

6.3 I-V curve stability for EUT testing

6.3.1 General

6.3.1.1 Overview

This subclause discusses basic recommendations for the stability of the I-V curve characteristics of the output of a PV array simulator, which may be affected by the EUT operational state and state changes, by the PV array simulator’s AC input conditions, and by other factors.

6.3.1.2 Characteristic and performance of PV array simulators for EUT tests

The EUT DC current and voltage fluctuate during MPPT or other characteristics of the PCE operation including dynamic power change in AC side fluctuation test. The PV array simulator’s I-V curve is expected to keep stable to simulate the actual photovoltaic array performance.

Recommended current and voltage accuracies for test performance are addressed in Annex A (informative) DC I-V curve accuracy against MPPT control.

Other recommendations such as static and dynamic characteristics and stability of PV array simulators are referred to IEC 62891.

6.3.1.3 MPPT power survey oscillation

The DC current from the PV array to the PCE fluctuates due to the maximum power point tracking control of the PCE. On the I-V curve, the DC voltage induced from PV array to PCE fluctuates in the opposite direction of the DC current variation.

The MPPT survey speed and current change step width depends on the design of the EUT control.

The PV array simulator output should maintain accurate tracking of the programmed I-V curve during the rapid load current changes demanded by the MPPT survey of the EUT.

See Annex A.

6.3.1.4 Utility frequency ripple voltage/current

In some PCE topologies, the DC input to the PCE has a ripple superimposed on it based on the AC line frequency (e.g. twice the line frequency for single phase inverters).

This ripple voltage can be quite large from the PV array to earth (common mode), but there may also be significant line to line ripple.

The utility-frequency ripple does not appear during the stable operation of three-phase PCE, because the summation of the balanced three phase power with the time keeps constant, whereas the single-phase power derived by multiplication of instantaneous voltage and current with the time fluctuates in twice the utility frequency.

In case of line to line short circuit failure protection or under voltage ride-through test in three phase system, the AC voltage waveform shifts to single phase operation and there appears the twice the utility frequency in DC side of the PCE. The PV array simulator output should maintain accurate tracking of the programmed I-V curve with this ripple voltage applied by the PCE.

See Annex B.

6.3.1.5 Quick power change in the UVRT test

During the UVRT test, AC output power suddenly reduces and then increases due to AC voltage test conditions.

In that situation, the DC side I-V characteristics should be stable as DC current reduces and DC voltage increases towards the open circuit voltage along the I-V curve.

The voltage increase rate and set-back rate for UVRT test depends on AC voltage change rate in the test.

UVRT test procedure is indicated in IEC TS 62910.

See Annex C.

6.3.2 DC irradiance change rate

6.3.2.1 Slow irradiance rising during sunrise

For the test of EUT automatic start in the morning, irradiance rising speed is controlled as slow as the real-world behavior.

In the early morning, the open circuit voltage of a PV array rises rapidly as irradiance increases.

Depending on the design of residential use or small-sized EUTs, control circuit power is supplied from the PV array before the interconnection to the utility grid.

Detecting that the DC input voltage rises up to the design threshold of the EUT, the control circuit begins to operate.

At that moment, the I-V curve voltage rapidly reduces because the irradiance is not enough to generate and deliver the sufficient EUT control power to make the EUT stand-by.

This causes a number of starts and stops in the PCE control because the I-V curve is unstable with respect to available current. For tests of the start-up operation characteristics of the EUT, certain resolution and accuracy of the output voltage for low irradiance is recommended.

For the operation in this area of I-V curve, the PV array simulator should have sufficient resolution with current stability for quick voltage change to replicate these current/voltage characteristics.

Typically, large EUT use their circuit control power from the utility all the time. In that case, the automatic start sequence is activated by detecting that the DC input voltage is risen-up to the design threshold of the EUT, to begin feeding gate signals from the control system to switching devices.

In that case, the start and stop operation cycle does not occur, but still, open voltage rise-up speed in the morning should be simulated by the PV array simulator.

For testing the compliance accuracy in the range of morning startup and evening stop down period, testing condition and sequence are indicated in EN 50530.

As a testing procedure reference for rate of change of irradiance, EN 50530 specifies 0,1 W/m^2·s both for ramp up and ramp down for start-up and shut down sequence measurement as the test pattern.

See Annex D.

6.3.2.2 Slow irradiance falling during sunset

The open circuit voltage of the PV array decreases rapidly as irradiance falls in the sunset, when the MPP part of the I-V curve is under the voltage axis. It sometimes causes a repetition of start and stop in the PCE control, because the I-V curve is unstable to the current rise.

For the testing of PCE stable operation to shut down for the sunset time, irradiance parameter decreasing sequence is performed in the reverse way for the morning duration,

In the same manner, the PV array simulator should have sufficient resolution with current stability for quick voltage change to replicate these current/voltage characteristics, in the testing condition of low irradiance parameter.

See Annex D.

6.3.2.3 Rapid irradiance fluctuation due to cloud cover

Irradiance may change rapidly due to cloud cover or cloud-edge enhancement events. This causes correspondingly rapid fluctuations in the DC voltage and current from the PV array.

The EUT is expected to operate in that situation and so the DC power simulator should be able to change the available power to the EUT at similar or faster rates if such conditions are a required part of a test. For example, for dynamic MPPT testing, IEC 62891 requires the MPP to be changed at rates of up to 100 W/m^2 per second.

The largest irradiance change rate is estimated to be 0 % to 100 % in 2 s which is sufficiently fast for known operating conditions and locations. See Annex E.

For transitional irradiance change speed, some numbers are given as examples. Further measurements for quicker irradiation change may be used as a worst-case scenario.

6.4 DC power simulator performance and characteristics for utility interaction tests

The characteristics and performance of DC power simulators that are important for the correct and effective application of testing of PCE depend on the specifics of the test being considered.

Recommendations for desired characteristics are indicated in Table 1 through Table 22 for the same utility interaction tests that are covered in the similar tables in IEC TS 63106-1 for AC simulators. Tests for which there is no corresponding table for AC simulators in IEC TS 63106-1 are covered in 6.5

The characteristics recommended in Table 1 through Table 22 should be maintained over the full range of conditions as applicable for the test specification.

NOTE Abbreviations indicated in Table 1 through Table 22 are: P for active power, Q for reactive power, S for apparent power, PF for power factor, OV for over voltage, UV for under voltage, OF for over frequency, UF for under frequency, Iq for reactive current and ROCOF for rate of change of frequency.

Table 1 – Grid qualification/Requalification – In-range AC voltage before connection/reconnection

Short description of test	Before starting the test, the DC power simulator operates at the set open circuit voltage point without current. After increasing/decreasing AC voltage and crossing the AC voltage threshold for the interconnection, EUT starts generation and DC current rises relevant to the output power of the EUT. Typically, not required to be done at full power and often signal injection methods are allowed.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power may be signal level, or a small percentage of EUT rated output, allowing a range of techniques.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT starting and operating behaviour on DC side is real and reliable.	Testing time is limited by the weather, with daytime-stable irradiation condition. I-V characteristic is limited depending on the PV module type and array circuit flexibility.
PV array simulator	Good	EUT starting and operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible issues with step change response on EUT start-up. Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

**Table 2 – Grid qualification/Requalification –
In-range AC frequency before connection/reconnection**

Short description of test	Before starting the test, the DC power simulator operates at the set open circuit voltage point without current. After increasing/decreasing AC frequency and crossing the AC frequency threshold for the interconnection, EUT starts generation and DC current rises relevant to the output power of the EUT. Typically, not required to be done at full power and often signal injection methods are allowed.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power may be signal level, or a small percentage of EUT rated output, allowing a range of techniques.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial. Possible if testing at low power.	EUT starting and operating behaviour on DC side is real and reliable.	If testing at significant power levels, need adequate stable irradiance.
PV array simulator	Good	EUT starting and operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible issues with step change response on EUT start-up. Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test). .

Table 3 – Power capability: Nameplate P, Q, S under normal and near-normal grid conditions

Short description of test	After the starting of EUT, the EUT controls the output power up to the rated maximum power point of the configured PV array. EUT is checked to operate at rated output active power under normal and near-normal grid conditions. EUT operation set point or grid voltage is adjusted, to check that the EUT is operating at rated output reactive and apparent power as designed.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the EUT rated AC output across a range of power factors that may include 100 % reactive power and near-zero DC input power.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT starting and operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance. Testing time is limited by the weather, with daytime-stable irradiation condition.
PV array simulator	Good	EUT starting and operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 4 – Power capability: Limitation of P/Q/S/PF by setpoint

Short description of test	After the starting of EUT, the EUT controls the output power up to the rated maximum power. Then EUT operation set point is adjusted, to check that the EUT is operating at output active, reactive, apparent power, or power factor at the set values.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the EUT rated output.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance. Testing time is limited by the weather, with daytime-stable irradiation condition.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 5 – Power capability: Ramp rate or soft start time-developing magnitude by set rate

Short description of test	Before the AC connection, the DC simulator is set to provide adequate voltage and power for the EUT to provide full AC output power. The EUT is started by manual command or automatic sequence to check that the EUT implements the expected ramp rate or soft start rate of AC output power.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the EUT rated output.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance. Testing time is limited by the weather, with daytime-stable irradiation condition.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 6 – Grid protection tests – AC over-voltage (OV) and under-voltage (UV) trip tests

Short description of test	With the EUT injecting energy into the AC power simulator, the AC voltage in all phases (symmetrical) or on one or two phases (asymmetrical) is raised or lowered far enough above or below the nominal interconnection voltage that the EUT's grid OV or UV protection should trip instantly if it exceeds a specified time. Typically, not required to be done at full power and often signal injection methods are allowed.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power may be signal level, or a small percentage of EUT rated output, allowing a range of techniques.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial. Possible if testing at low power.	EUT operating behaviour on DC side is real and reliable.	If testing at significant power levels, need adequate stable irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 7 – Grid protection tests: OF/UF trips

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency is raised or lowered far enough above or below the nominal interconnection frequency that the EUT's grid OF or UF protection should trip, in a specified time. Typically, not required to be done at full power and often signal injection methods are allowed.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power may be signal level, or a small percentage of EUT rated output, allowing a range of techniques.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial. Possible if testing at low power.	EUT operating behaviour on DC side is real and reliable.	If testing at significant power levels, need adequate stable irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 8 – Grid protection tests: Anti-islanding

Short description of test	With the EUT injecting energy to the AC power simulator and L-C-R loads, the AC voltage and frequency are set to nominal values. EUT generation and load consumption powers are adjusted to balanced and designated near-balanced points. This is typically required to be done with commanded/set power levels (i.e. MPPT turned off). When the AC power simulator is disconnected, the EUT and balanced load form an island. The EUT is required to detect and de-energize the island. Typically required to be done at full power and reduced power levels, but some standards allow simulation methods to be used. For the PCE with grid-support functions (e.g. active and reactive power control as functions of grid voltage or frequency, etc.), some standards require the anti-islanding test to be conducted with and without the functions enabled. Anti-islanding testing is specified in (e.g.) IEC 62116.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the EUT output power range required for the anti-islanding tests.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	None

Table 9 – Grid protection tests: Rate of Change of Frequency (ROCOF) trips

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency is quickly raised or lowered with a designated slope of frequency vs. time. The EUT is required to trip instantly if the ROCOF exceeds certain limits. Typically, not required to be done at full power and often signal injection methods are allowed.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power may be signal level, or a small percentage of EUT rated output, allowing a range of techniques.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial. Possible if testing at low power.	EUT operating behaviour on DC side is real and reliable.	If testing at significant power levels, need adequate stable irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 10 – Grid protection tests: Open phase

Short description of test	With the EUT injecting energy to the AC power simulator, a selected single-phase line in multi-phase system of the EUT output is disconnected. The remaining two-phase lines remain energized. Typically, not required to be done at full power and often signal injection methods are allowed.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power may be signal level, or a small percentage of EUT rated output, allowing a range of techniques.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial. Possible if testing at low power.	EUT operating behaviour on DC side is real and reliable.	If testing at significant power levels, need adequate stable irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 11 – Power quality tests: Current harmonics, inter-harmonics, THDi

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency and voltage is kept steady. Typically, required to be done at full and reduced power. The total harmonic current distortion, low order (typically n=2-40) current harmonics, and in some standards the higher order harmonics and interharmonics, and are measured. In some designs, the MPPT operation may impact current harmonics, and some standards may specifically require MPPT to be enabled and use of a PV array simulator.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
I-V curve setting flexibility	If use of a PV array simulator is required: Output I-V curve is adjustable for required V_{oc}, I_{sc}, V_{mpp}, $I_{mpp,}$ FF that fit DC input voltage/current range window including rated value of the EUT.		
I-V curve stability	If use of a PV array simulator is required: Output I-V curve stands the same on the set characteristic continuously across the range of DC current from zero to the required EUT power with the relevant DC voltage.		
Power	Simulator power should cover the EUT output power required for the grid protection tests.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good. May be required in some cases.	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is required to be turned on

Table 12 – Power quality tests: Flicker (continuous)

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency and voltage is kept steady. This test measures the AC voltage flicker caused by the EUT under test conditions. The data is then used in installation-specific assessments to predict actual flicker levels under field conditions. Typically, the test is required to be done at full power. Some standards may require MPPT to be enabled, and in some cases that may necessitate use of a PV array or PV array simulator.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
I-V curve setting flexibility	If use of a PV array simulator is required: Output I-V curve is adjustable for required V_{oc}, I_{sc}, V_{mpp}, $I_{mpp,}$ FF that fit DC input voltage/current range window including rated value of the EUT.		
I-V curve stability	If use of a PV array simulator is required: Output I-V curve stands the same on the set characteristic continuously across the range of DC current from zero to the required EUT power with the relevant DC voltage.		
Power	Simulator power should cover the EUT output power required for the grid protection tests.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good. May be required in some cases.	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is required to be turned on.

Table 13 – Power quality tests: Current inrush (at connection switch close)

Short description of test	Before injecting energy to the AC power simulator, the AC frequency and voltage is kept steady. The connection switch to the grid is closed and the inrush current waveform with peak, time to peak, and defined cycle period-RMS is recorded. As the inrush occurs before the EUT has time to qualify the AC grid voltage and begin operating, the DC simulator does not need to provide full power (just enough power to operate DC-powered control circuits).		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power adequate for DC-powered control circuits.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Good	EUT operating behaviour on DC side is real and reliable.	None
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	None

Table 14 – Power quality tests: AC output current imbalance

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency and voltage is kept steady. Three phases of voltage are kept balanced and the EUT AC output current imbalance is measured. Typically, required to be done at full power and in some standards at reduced power.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the EUT output power required for the grid protection tests.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 15 – Power quality tests: Transient over-voltage (TrOV) on load dump

Short description of test	With the EUT injecting energy into the AC power simulator, the connection to the simulator is suddenly opened, which tends to cause a transient overvoltage on the EUT output terminals. In many standards the magnitude and duration of that overvoltage transient are subject to limits. In some designs, the behaviour on the DC side may impact the results, and use of a PV array or PV array simulator may be required by some standards. Full power is required, and DC input voltage to the EUT may be required to be set to prescribed levels.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
I-V curve setting flexibility	If use of a PV array simulator is required: Output I-V curve is adjustable for required V_{oc}, I_{sc}, V_{mpp}, I_{mpp}, FF that fit DC input voltage/current range window including rated value of the EUT.		
I-V curve stability	If use of a PV array simulator is required: Output I-V curve stands the same on the set characteristic continuously across the range of DC current from zero to the required EUT power with the relevant DC voltage.		
Power	Simulator power should cover the EUT output power required for the grid protection tests.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance. No ability to set DC voltage to a prescribed level.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Quick reduction of EUT input power to zero due to square-shaped I-V curve may make an additional cause of EUT operation stop, depending on the maximum power tracking performance and step response of the power supply.

Table 16 – Grid support tests: UV/OV ride-through with/without Iq injection

Short description of test	With the EUT injecting energy to the AC power simulator, the AC voltage is quickly dipped below or raised above the normal operating range on one, two or all three phases (symmetrical), for a defined period of time, and then returned to the normal operation range, or in some standards, to an intermediate value. The EUT should be able to remain connected, and depending on the grid code requirements, may be required to continue to inject active current and/or to inject reactive current, into the AC power simulator. The EUT shall resume normal operation after the simulated UV/OV event. In some designs, the behaviour on the DC side may impact the results, and use of a PV array or PV array simulator may be required by some standards. Full power is required.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
I-V curve setting flexibility	If use of a PV array simulator is required: Output I-V curve is adjustable for required V_{oc}, I_{sc}, V_{mpp}, $I_{,}$ FF that fit DC input voltage/current range window including rated value of the EUT.		
I-V curve stability	If use of a PV array simulator is required: Output I-V curve stands the same on the set characteristic continuously across the range of DC current from zero to the required EUT power with the relevant DC voltage.		
Power	Simulator power should cover the full EUT output power required.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is required to be turned on.

Table 17 – Grid support tests: UF/OF ride-through

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency is varied above or below the normal operating range, for a defined period of time, and then is returned to the normal operation range. The EUT should be able to remain connected, continue to inject active power, depending on the grid code requirements, and then resume normal operation after the simulated UF/OF event.		
Important DC. power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the full EUT output power required.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 18 – Grid support tests: ROCOF ride-through

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency is quickly raised or lowered with a designated slope of frequency vs. time. The EUT is required to stay connected for ROCOF up to certain limits. Typically, not required to be done at full power but main circuit should be energized.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power may be a small percentage of EUT rated output, allowing a range of techniques.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	If testing at significant power levels, need adequate stable irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 19 – Grid support tests: Phase-jump ride-through

Short description of test	With the EUT injecting energy to the AC power simulator, the AC voltage phase is quickly changed to a designated leading and lagging phase angle and then is returned to the original phase angle after a specified time. Typically, required to be done at partial power, and in some standards may be required to be done at full power. Some standards may allow signal injection methods.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the EUT output power required for the test, which may be zero or very low if simulation is allowed.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial. Possible if testing at low power.	EUT operating behaviour on DC side is real and reliable.	If testing at significant power levels, need adequate stable irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test)

Table 20 – Grid support tests: P (f), PF (P, V), Q (V), P (V)

Short description of test	With the EUT injecting energy to the AC power simulator, the AC frequency, or voltage is changed to a value defined by each required characteristics of the function for active or reactive power control of EUT. - In P(f) test, frequency is changed to measure output power vs. frequency control characteristics of EUT. - In PF(P) test, EUT output power is changed to measure output power factor vs. active power control characteristics. - In PF(V) test, AC voltage is changed to measure power factor vs. voltage control characteristics of EUT. - In Q(V) test, AC voltage is changed to measure reactive power vs. voltage control characteristics of EUT. - In P(V) test, AC voltage is changed to measure active power vs. voltage control characteristics of EUT.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the full EUT output power required.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Poor	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance. Many of these tests require stable conditions for much longer than can be relied on from a PV array.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test) This may be more significant when operating the EUT at high levels of reactive power output, due to DC input current ripple and MPPT interaction with the steep I-V curve of the power supply.

Table 21 – External command response tests: Magnitude accuracy for P/Q/S/PF by setpoint

Short description of test	With the EUT injecting energy to the AC power simulator, EUT output power, reactive power, or power factor is changed to, and shall remain at the set point requested by an external command signal. Typically, required to be done at full and reduced power.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the full EUT output power required.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test) This may be more significant when operating the EUT at high levels of reactive power output, due to DC input current ripple and MPPT interaction with the steep I-V curve of the power supply.

Table 22 – External command response tests: Response to external setpoint changes (response time, settling time test)

Short description of test	With the EUT injecting energy to the AC power simulator, EUT output power, reactive power, or power factor is changed to, and shall remain at stay at the set point requested by an external command signal. The time to respond to the command and/or settle at the new value is measured. Typically, required to be done at full and reduced power.		
Important DC power simulator attributes for this specific test	Important aspects of the simulator attribute		
Power	Simulator power should cover the full EUT output power required.		
Usability of DC power simulator types	Usability	Capabilities and benefits	Drawbacks
PV array	Partial	EUT operating behaviour on DC side is real and reliable.	Need full power array and full irradiance, or oversized array with adequate irradiance.
PV array simulator	Good	EUT operating behaviour on DC side is reliable.	None
DC power supply	Good	Stable and variable DC operating voltage, current, and power.	Possible mis-operation of the EUT if MPPT is turned on (but that is not required for this test) This may be more significant when operating the EUT at high levels of reactive power output, due to DC input current ripple and MPPT interaction with the steep I-V curve of the power supply.

6.5 Additional tests conducted with DC power simulators

6.5.1 General

Table 23 describes DC PV-specific test items that supplement the tests described in 6.4.

Table 23 – Test items and DC power simulators application for PCE

No.	Test item	Applicability		
		PV array	**PV array simulator**	**DC power supply**
1	PCE operational stability with sudden irradiance changes (due to movement of sunshine between clouds)	Partial Quick covering and clearing the PV array surface by opaque material may be possible, but does not provide control of irradiance level.	Good Quick movement of I-V characteristic curve by control software is implemented.	Partial Some DC power supplies may be able to be programmed for sudden changes in voltage level and current limit, but I-V curve simulation is not available.
2	Automatic start and stop operation with gradual irradiance changes (representing morning and evening conditions)	Good Actual sunrise and sunset in the field is realized, but full-size array is not always available	Good Slow movement of I-V characteristic curve with irradiance change is realized.	Partial Slow adjustment of voltage and current limits are possible, especially with programmable power supplies.
3	PCE DC to AC power conversion efficiency measurement	Partial Actual PV array in the field may be used, but it needs a full-sized array and constant full irradiance, or an over-sized array and adequate irradiance.	Good EUT DC input stays on specific I-V characteristic curve with irradiance parameter	Good Stable and variable DC operating voltage, current, and power. EUT may have MPPT control mode disabled, and constant DC voltage mode enabled.
4	PCE maximum power point tracking efficiency	None Use of an actual PV array does not provide the level of stability and control required. Disallowed by IEC 62891.	Good EUT input stays on specific I-V characteristic curve with irradiance parameter.	None Square voltage v.s. current characteristic is not suitable for MPPT control accuracy test. So, it is disallowed by IEC 62891.
5	PCE total power conversion efficiency measurement	None Actual PV array in the field may be used, but full-size array and constant irradiance is not always available. PCE maximum power point tracking efficiency test is contained in total power conversion efficiency measurement. So, it is disallowed by IEC 62891.	Good EUT input stays on specific I-V characteristic curve with irradiance parameter.	None Square voltage v.s. current characteristic is not suitable for MPPT control accuracy test, that is included in the PCE total conversion efficiency test. So, it is disallowed by IEC 62891.

6.5.2 PCE operational stability with sudden irradiance changes (due to movement of sun between clouds)

PCE operational stability is validated by simulating sudden changes to the PV output I-V curve characteristic, as controlled by the irradiance parameter.

When the irradiance changes, the MPP voltage changes and the I-V curve raises and lowers along the axis of current, causing the EUT to adjust its MPP voltage and output power.

The irradiance change rate is specified by the testing procedure.

6.5.3 Automatic start and stop operation with gradual irradiance changes (representing morning and evening conditions)

PCE rated start and stop thresholds are validated by simulating very gradual irradiance changes associated with morning start-up and evening shut-down conditions, as controlled by the irradiance parameter.

As the irradiance increases (morning condition), the open circuit voltage and available current increases until the PCE has sufficient power to begin conversion.

Conversely, decreasing irradiance representing evening operation causes the inverter to stop producing power when there is no sufficient voltage and current.

The irradiance rate of change is specified by the testing procedure.

6.5.4 PCE DC to AC power conversion efficiency measurement

PCE DC to AC power conversion efficiency is validated using any type of DC power simulator. However, if a PV array is used, irradiance shall be both adequate and stable, so a PV array simulator or DC power supply is recommended.

The maximum power point tracking function of the EUT is permitted to be disabled if applicable.

The DC input power is measured across a range of PV array output voltage and power levels.

The measured DC input power and AC output power are used to calculate efficiency at each power level, and set of weighting factors are applied to calculate a weighted average power conversion efficiency.

Detailed test specifications are given (e.g.) in IEC 61683.

6.5.5 PCE maximum power point tracking efficiency measurement

The PCE maximum power point tracking efficiency is validated using a PV array simulator.

The maximum power point tracking function of the EUT should be enabled.

The DC input voltage and power is parameterized representing a the I-V curve characteristics of a selected PV array.

The actual measured power operating on the MPPT point is compared to the ideal value of the I-V curve MPP.

For the case where there is a long cable or bus-bar supplying the DC power from the PV simulator to the EUT, measurement and evaluation at the PV simulator DC output terminal is recommended because a large uncertainty in the tracking efficiency estimation is introduced when applying the DC voltage drop compensation.

The I-V curve control and measurement accuracy should be calibrated for the static and dynamic curve characteristics as controlled by the irradiance parameter.

Detailed specifications are given (e.g.) in IEC 62891.

NOTE As MPPT performance has reached very high levels (99,9 % efficiency for example) the accuracy of the simulator I-V curve and related voltage and current measurements becomes increasingly important, and can be difficult to achieve given available test equipment.

6.5.6 PCE total power conversion efficiency measurement

This test measures the total power conversion efficiency of the PCE by combining power conversion efficiency (6.5.4) and MPPT efficiency (6.5.5), into a single test.

The PCE total power conversion efficiency is validated using a PV array simulator. The maximum power point tracking function of the EUT should be enabled. The DC input voltage and power is parameterized representing a range of PV array outputs and compared with measured EUT output voltage and power.

6.6 Avoidance measures of transient impact to EUTs

For the tests such as grid protection tests or grid support tests, DC power supplies or PV array simulators should be designed to avoid DC overvoltage impacts to EUTs that may lead to unwanted EUT break down or malfunctions.

Annex A
(informative)

DC I-V curve dynamic accuracy against MPPT control

A.1 General

The current and voltage of the DC simulator will vary along a defined I-V curve as the EUT controller searches for the maximum power point. This annex discusses the dynamic accuracy aspects of the DC simulator's current and voltage output during MPPT testing.

A.2 Example of DC I-V curve stability for MPPT properties

A.2.1 MPPT control

MPPT control is often achieved using the mountain climb method. In the method, the PCE's MPPT algorithm controls the input DC current and then monitors the input power. The current is adjusted in a step-wise manner to determine whether or not the power has increased, and in this way, locates the MPP.

Figure A.1 shows the voltage and current variation by MPPT control around the maximum power point of the PV array's I-V curve.

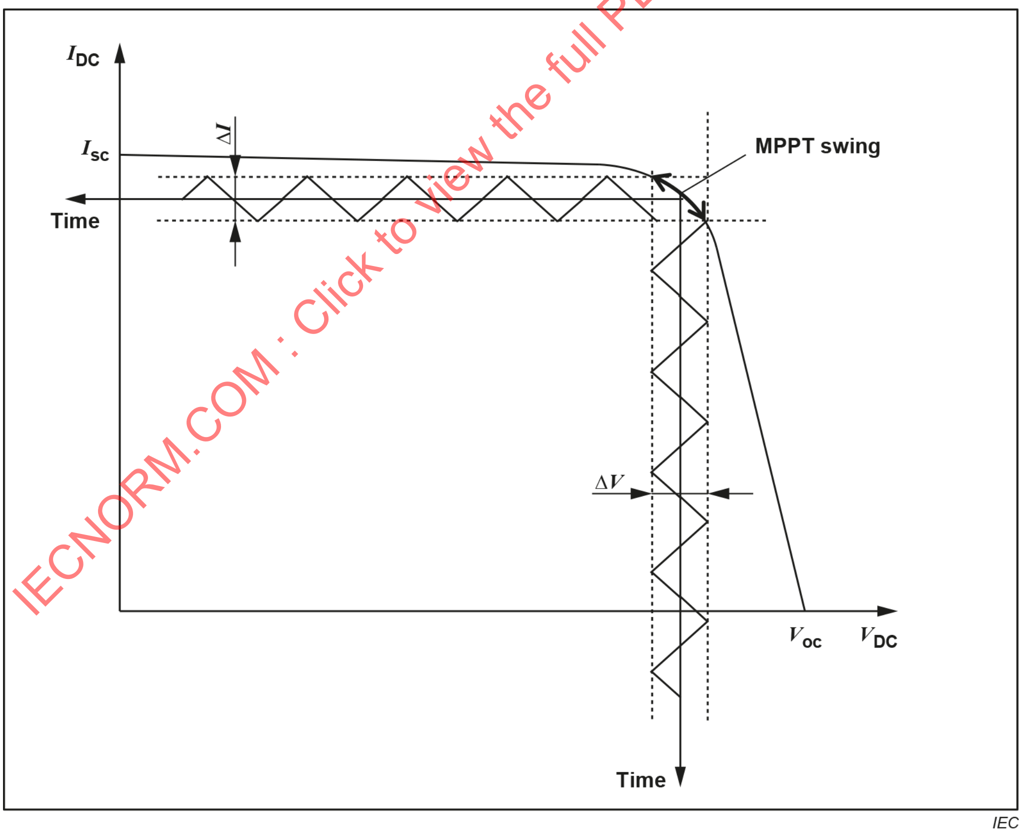

Figure A.1 – Voltage and current swing by MPPT control on I-V curve around MPP

A.2.2 Recommended stability of operation on the I-V curve

The DC simulator is recommended to maintain the I-V curve current and voltage values to within ±3 % of reference values when the reference fluctuates by up to 10 % of the rated EUT MPPT current within a period reflecting wide range of inverter designs of MPP tracking speed, sometimes up to the area of tens of kHz, for example.

A.2.3 Recommended I-V curve resolution

Figure A.2 shows an example in which the DC voltage is higher than the MPP of the PV array. In this case, the current variation is large for a small variation of the voltage. The difference between the adjacent current references on the I-V point data table in the EUT control system is too large, and there exists no operational voltage point for the operating current of the EUT. As a result, the voltage resolution should be small enough both for quasi-constant voltage area and quasi-constant current area.

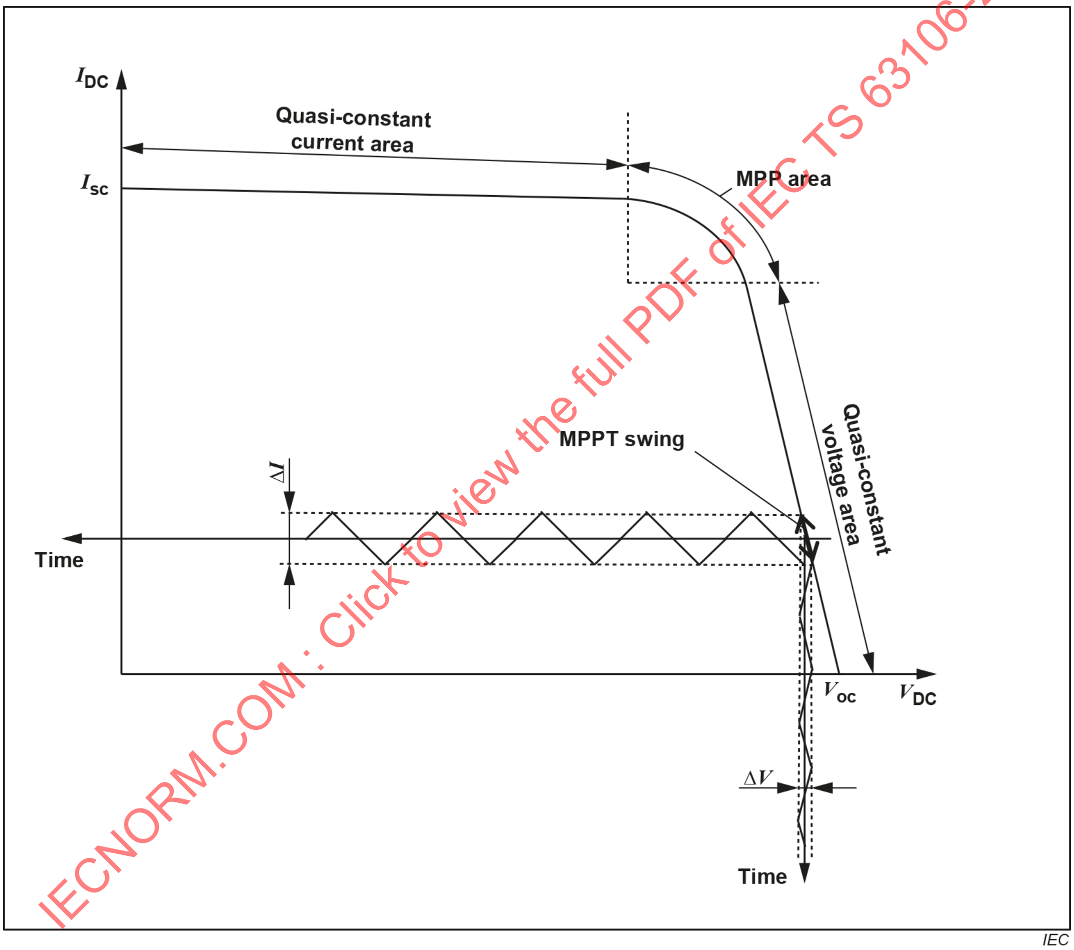

Figure A.2 – Current and voltage swing by MPPT control on I-V curve below MPP

A.2.4 Use of DC power supply as an input of EUT

For tests that do not measure MPPT efficiency or other precise characteristics of the EUT, a more typical DC power supply with constant voltage control and maximum current limitation is suitable for use. Such test items include temperature rise tests, environmental durability tests, enclosure rain shower tests with EUT in operation, and similar conditioning tests. For these tests, the EUT control may be switched to constant voltage mode or other means as determined by the EUT manufacturer. Figure A.3 shows an example of DC power supply I-V curve characteristics and MPPT movement.

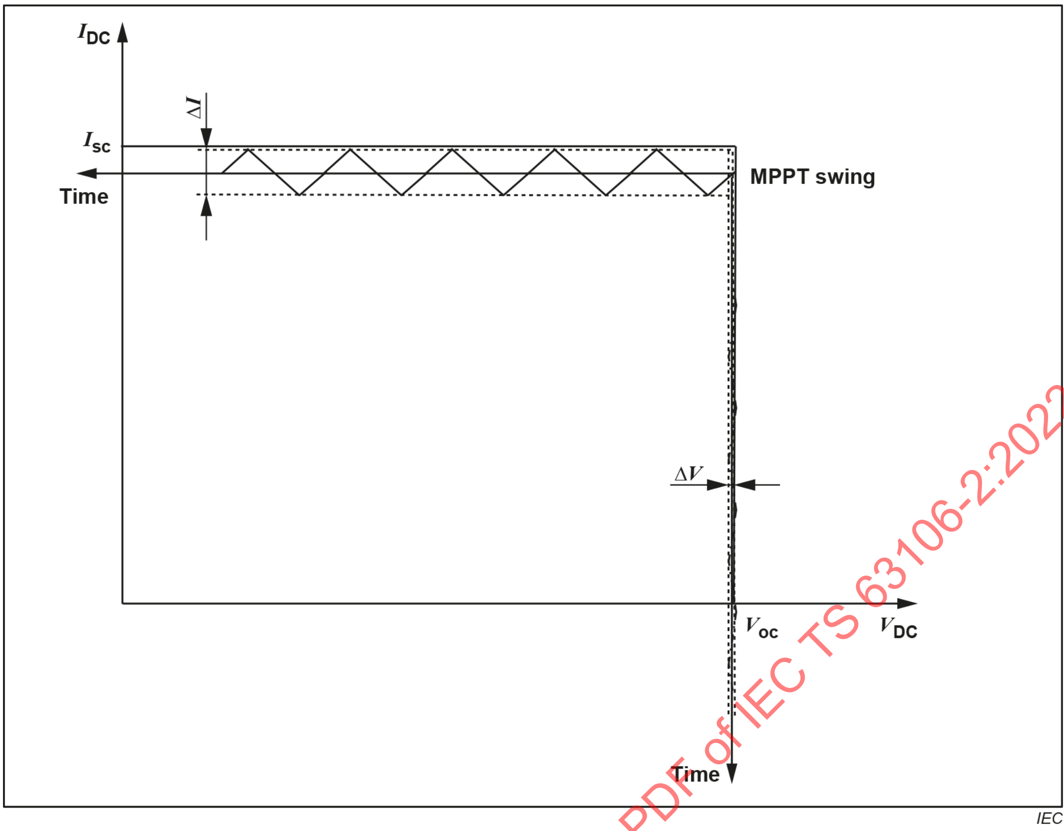

Figure A.3 – Current and voltage swing by MPPT control on I-V characteristic curve of DC power supply

Annex B
(informative)

DC power simulator stability against utility-frequency ripple voltage/current

B.1 General

As the DC simulator current flows into the EUT, the voltage and current fluctuates according to the DC ripple component. In this annex the dynamic accuracy of the I-V curve control when subjected to the DC ripple component is described.

B.2 Example of twice the utility-frequency ripple voltage/current

B.2.1 Twice the utility-frequency ripple voltage/current

The DC power from PV array to PV inverter fluctuates due to DC to AC power conversion. With some single phase PCE, the fluctuation is called 'twice the utility-frequency ripple component'. Figure B.1 shows DC current and voltage ripple on this type of single-phase GCPC. In this manner, the EUT DC input voltage and current swings back and forth from the ideal MPP of the I-V curve. When the DC side capacitor in the EUT main circuit is not large enough, the ripple voltage is large, reduces the mean power extracted from the PV array, and therefore negatively impacts to affect the system efficiency. In order to evaluate the single phase EUT performance, it is recommended that the DC power simulator is able to maintain stability when subjected to the twice the utility frequency ripple.

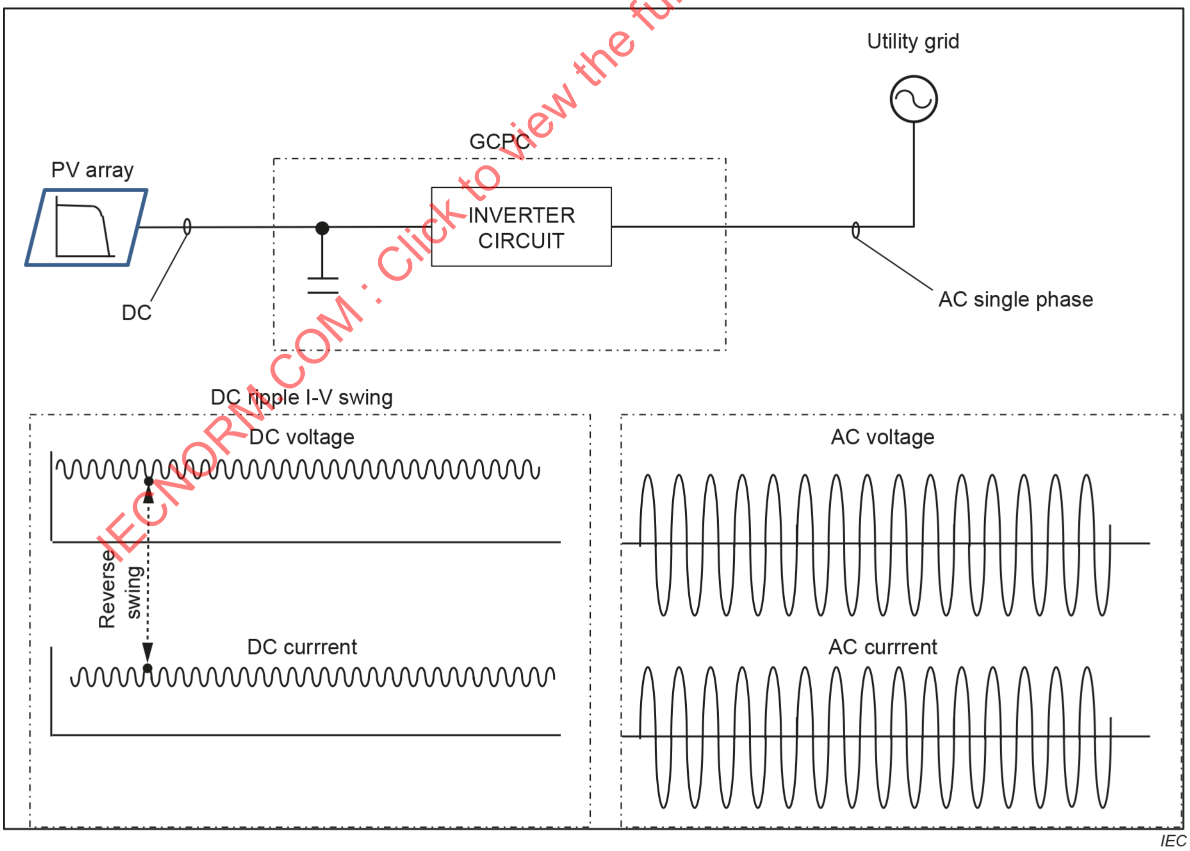

Figure B.1 – DC current and voltage ripple on single-phase GCPC

For three phase GCPCs being tested for UVRT operation in response to two-line short circuit fault, the residual voltage remains in single phase operation and the twice the utility-frequency ripple component appears on the DC side. When the AC utility grid power frequency is 50 Hz, the ripple frequency on the DC side is 100 Hz. In order to evaluate the UVRT performance of the EUT, it is recommended that the DC power simulator maintains stable operation during the voltage sag and recovery period. See Figure B.2.

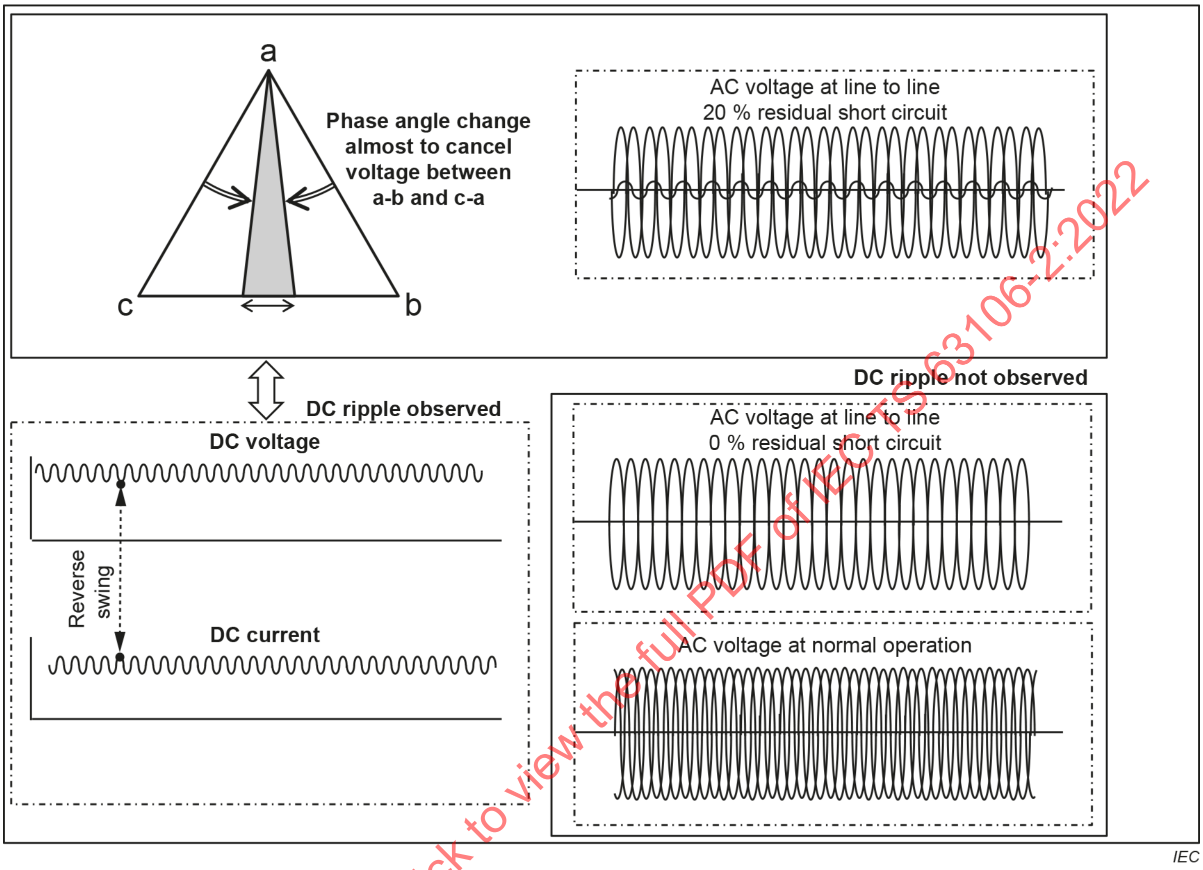

Figure B.2 – DC current and voltage ripple on three-phase GCPC with UVRT test

For PV array simulators in particular, it may be important for some tests for the simulator to have the resolution and stability for the I-V curve simulation to track this ripple.

B.2.2 Stability of I-V curve for the DC ripple

Figure B.3 shows the voltage and current swing in the MPP survey or forced-reduction of output power, resulting from output control or UVRT test. When the EUT operating voltage range is higher than the MPP point, the ratio of current swing to voltage swing is large. Relevant operating point should be maintained on the stable I-V curve for the EUT ripple swing.

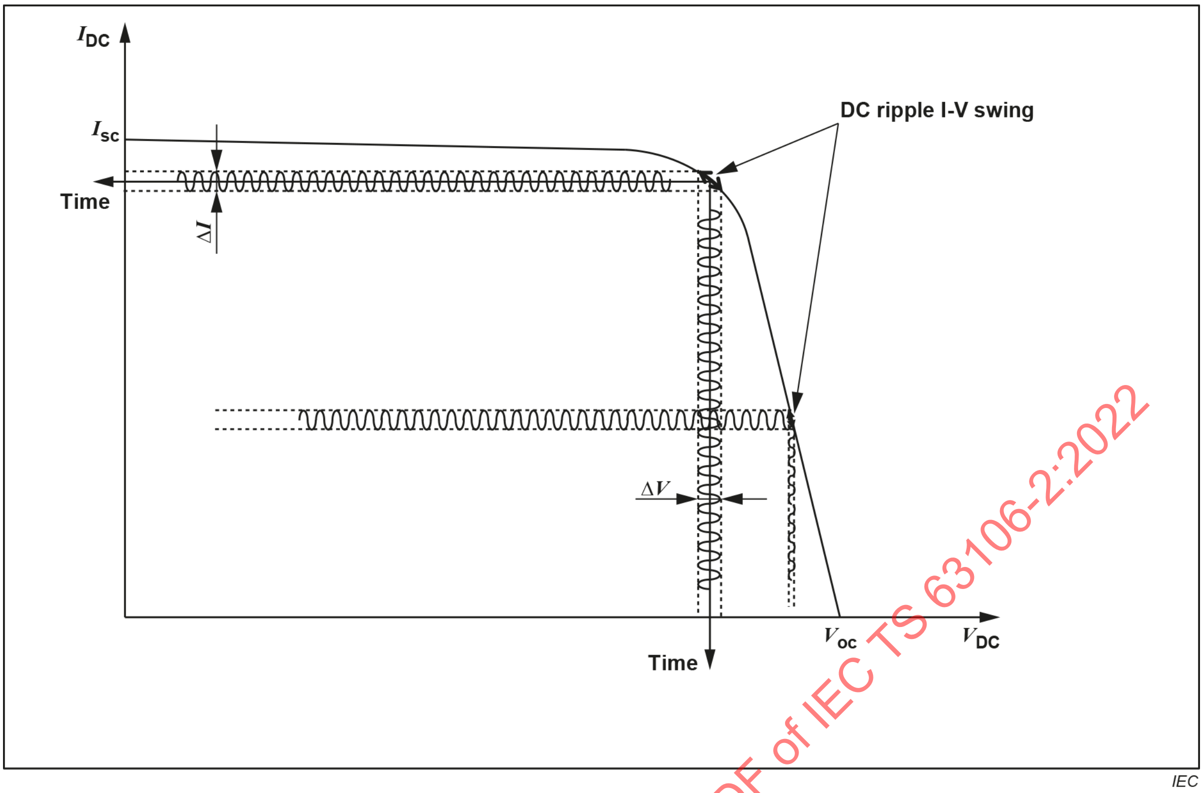

Figure B.3 – DC ripple I-V swing on I-V curve of PV array

Annex C
(informative)

PV array simulator I-V curve stability against quick power change in UVRT test

C.1 General

The PV array simulator output voltage and current changes stepwise in the UVRT test. The trajectory of DC current and DC voltage should move along the I-V curve. Dynamic accuracy of the I-V curve current and voltage when subjected to UVRT tests is described. The test procedure of UVRT is specified in IEC TS 62910.

C.2 DC voltage/current shift by withdrawing power change in UVRT test

The DC power from the PV array to the EUT changes due to the change of the AC voltage on the output side of the EUT. When in the quasi-constant voltage region of the I-V curve, the inclination of the current (I) is steep, and the DC voltage current rate of change is large.

Such cases tend to occur when the I-V curve fill-factor is large. The I-V curve dynamic response in that transition state should be stable enough not to have nuisance oscillation caused by lack of the PV array simulator's transient tracking performance. The issue is that the current and voltage value oscillates significantly between zero and the I-V curve levels. Small oscillations due to the AC power simulator control may not affect the UVRT test.

Figure C.1 shows the DC input voltage/current transition during a zero-voltage ride through test with a sudden current decrease.

Figure C.2 shows the DC input voltage/current transition during a zero-voltage ride through test with sudden current recovery.

Figure C.3 shows the DC input voltage/current range on the I-V curve and the EUT operating area, with both a successful and unsuccessful UVRT transition.