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TECHNICAL SPECIFICATION

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Utility-interconnected photovoltaic inverters – Test procedure for over voltage ride-through measurements

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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UTILITY-INTERCONNECTED PHOTOVOLTAIC INVERTERS – TEST PROCEDURE FOR OVER VOLTAGE RIDE-THROUGH MEASUREMENTS

FOREWORD

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

Draft	Report on voting
82/1926/DTS	82/1960/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.

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UTILITY-INTERCONNECTED PHOTOVOLTAIC INVERTERS – TEST PROCEDURE FOR OVER VOLTAGE RIDE-THROUGH MEASUREMENTS

1 Scope

This document provides a test procedure for evaluating the performance of Over Voltage Ride-Through (OVRT) functions in inverters used in utility-interconnected photovoltaic (PV) systems.

This document is most applicable to large systems where PV inverters are connected to utility high voltage (HV) distribution systems. However, the applicable procedures may also be used for low voltage (LV) installations in locations where evolving OVRT requirements include such installations, e.g. single-phase or 3-phase systems.

Fundamentally, the assessed OVRT performance is valid only for the specific configuration and operational mode of the inverter under test. Separate assessment is required for the inverter in other factory or user-settable configurations, as these may cause the inverter OVRT response to behave differently.

The measurement procedures are designed to be as non-site-specific as possible, so that OVRT characteristics measured at one test site, for example, can also be considered valid at other sites.

This document is for testing of PV inverters, though it contains information that may also be useful for testing of a complete PV power plant consisting of multiple inverters connected at a single point to the utility grid. It further provides a basis for utility-interconnected PV inverters numerical simulation and model validation.

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 61400-21-1:2019, *Wind energy generation systems – Part 21-1: Measurement and assessment of electrical characteristics – Wind turbines*

IEC TS 61836:2016, *Solar photovoltaic energy systems – Terms, definitions and symbols*

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

IEC TS 63106-2:2022, *Simulators used for testing of photovoltaic power conversion equipment – Recommendations – Part 2: DC power simulators*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the terms, definitions, symbols and abbreviated terms 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 Terms, definitions and symbols

3.1.1
over voltage ride-through
OVRT
capability of an inverter to continue generating power to connected utility grid during a limited duration voltage swell (see 3.1.28) of grid voltage

3.1.2
utility grid
grid for which an electrical utility is responsible

[SOURCE: IEC TS 61836:2016, 3.3.29.2]

3.1.3
tap-changer
apparatus or accessory for usually automatically changing transformer taps to regulate system voltage

3.1.4
inverter
electric energy converter that changes direct electric current to single-phase or polyphase alternating currents

[SOURCE: IEC TS 61836:2016, 3.2.15]

3.1.5
equipment under test
EUT
equipment on which these tests are performed and refers to the utility-interconnected PV inverter

3.1.6
$\mathbf{N_{EUT}}$
access point of the EUT during the test

3.1.7
P_n
rated power of EUT

3.1.8
proportionality constant K
K-factor
setting parameters affecting OVRT behaviour of the EUT regarding reactive current injection

3.1.9
photovoltaic array
mechanical and electrical assembly of photovoltaic modules, photovoltaic panels or photovoltaic sub-arrays and its support structure

[SOURCE: IEC TS 61836:2016, 3.3.59.1]

3.1.10
PV array simulator
simulator that has I-V characteristics equivalent to a PV array

[SOURCE: IEC TS 61836:2016, 3.5.3]

3.1.11
S_{EUT}
apparent short-circuit power at $\mathrm{N_{EUT}}$

$S_{\mathrm{EUT}} = I_{\mathrm{sc}} \times U_{\mathrm{N}}$,

I_{sc} refers to short-circuit current at $\mathrm{N_{EUT}}$ during the no-load test

3.1.12
single-phase fault
single-phase grounded fault

3.1.13
two-phase fault
two-phase short circuit fault or two-phase grounded fault

3.1.14
reactive power compensation device
device that is used to improve voltage regulation of the utility grid

3.1.15
grid fault simulator
simulator that has the ability to simulate static and dynamic voltage characteristics of different grid faults

3.1.16
over voltage fault
situation in which the amplitude of grid voltage is higher than normal working voltage range

3.1.17
AC main power port
point of connection of the AC grid to the EUT

3.1.18
DC main power port
point of connection of the DC power source to the EUT

3.1.19
voltage transformer
instrument transformer in which the secondary voltage in normal conditions of use, is substantially proportional to the primary voltage and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections

[SOURCE: IEC 60050-321:1986, 321-03-01]

3.1.20
current transformer
instrument transformer in which the secondary current in normal conditions of use, is substantially proportional to the primary current and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections

[SOURCE: IEC 60050-321:1986, 321-02-01]

3.1.21
tap transformer
device employing the principle of mutual induction to obtain different turn ratio, automatically changing transformer taps to regulate output voltage

3.1.22
short circuit
connection of comparatively low resistance accidentally or intentionally made between points on a circuit between which the resistance is normally much greater

3.1.23
back-to-back converter
power electronics equipment that converts input AC power to a DC link power with stable voltage or current, then converts the DC link power back to AC power

3.1.24
mechanical circuit breaker
mechanical switch that automatically interrupts the current of an overloaded electric circuit

3.1.25
step-up transformer
device employing the principle of mutual induction to obtain higher output voltage from low input voltage

3.1.26
A_{n}
voltage swell ratio

3.1.27
point of common coupling
PCC
point of a power supply network, electrically nearest to a particular load, at which other loads are, or may be, connected

Note 1 to entry: These loads can be either devices, equipment or system, or distinct customer's installations.

Note 2 to entry: In some applications, the term "point of common coupling" is restricted to public networks.

[SOURCE: IEC 60050-161:1990, 161-07-15]

3.1.28
voltage swell
temporary increase of the voltage magnitude at a point in the electrical system above a threshold

[SOURCE: IEC 61000-4-30:2015]

3.2 Abbreviated terms

AC	alternating current
A/D	analog to digital
DC	direct current
EUT	equipment under test
HV	high voltage
LV	low voltage
MP	measurement point
MV	middle voltage
OVRT	over voltage ride through
PCC	point of common coupling
PV	photovoltaic
RLC	resistor, inductor and capacitor
RMS	root mean square

4 Test circuit and equipment

4.1 General

The circuits and equipment described in this clause are developed to allow tests that simulate the full range of anticipated over voltage faults, including:

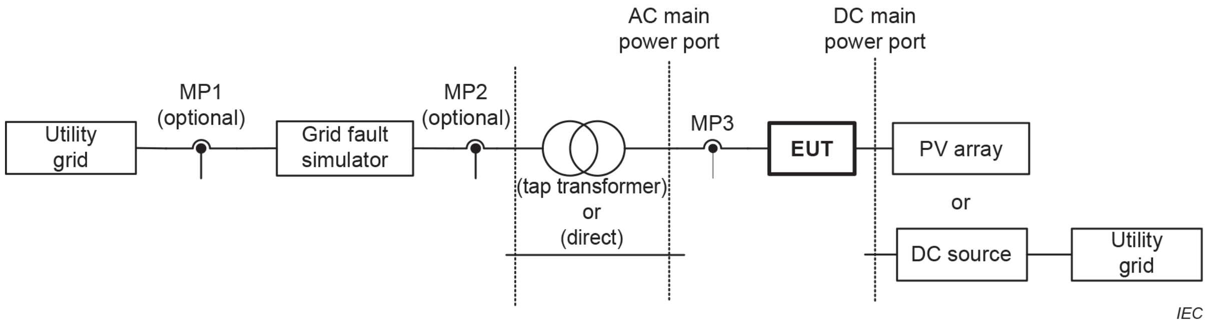
- Single-phase over voltage fault
- Two-phase over voltage fault
- Three-phase over voltage fault

NOTE Only single phase over voltage fault is suitable for single-phase EUT.

The RLC emulator and converter-based emulator described in 4.3.4.1 and 4.3.4.2 are informative examples of the grid fault simulator to simulate the over voltage fault, and these are not intended to restrict design flexibility. Other designs may be used to achieve equivalent test functionality.

4.2 Test circuit

The OVRT test circuit includes a PV array simulator (or PV array), a tap transformer, a grid fault simulator, the utility grid and the EUT. A PV simulator (or PV array) provides input energy for the EUT. The output of the EUT is connected to the grid via a grid fault simulator, as shown in Figure 1.



Key

MP1 measurement point between the grid and the grid fault simulator

MP2 measurement point at the high voltage side of the transformer

MP3 measurement point at the low voltage side of the transformer

Figure 1 – Testing circuit diagram

4.3 Test equipment

4.3.1 Measuring instruments

Waveform shall be measured by a device with memory function, for example, a storage or digital oscilloscope, or a high speed data acquisition device. Accuracy of the oscilloscope or data acquisition system should be at least 0,2 % of full scale. The sampling rate should be at least 10 kHz. The A/D converter resolution of the measurement device should have at least 12 bits (in order to maintain the required measurement accuracy).

Voltage transformers and current transformers are the required measuring instruments. The accuracy of the transducers should be 0,5 % of full scale or better. It is necessary to select the range of the measuring instruments depending on the normal value of the signal to be measured. The selected measuring range shall not exceed 150 % of the normal value of the measured signal. The accuracy of measuring devices requirements is shown in Table 1.

Table 1 – Accuracy of measurements

Measurement device	Accuracy
Data acquisition device	≤0,2 % full scale
Voltage transformer	≤0,5 % full scale
Current transformer	≤0,5 % full scale

4.3.2 DC source

A PV array or PV array simulator can be used as the DC source to supply input energy for the OVRT test. The DC source should be at least capable of supplying the EUT maximum input power and other power levels during the test, at the minimum and maximum input operating voltages of the EUT.

The PV array simulator should meet the requirements indicated in Clause 6 of IEC TS 63106-2:2022.

4.3.3 Multi-tap transformer

Different types of EUT may have different rated voltage of their AC main port. A multi-tap transformer is used to adjust the output voltage to match the voltage level of the grid fault simulator, if needed. The tap-changer for the multi-tap transformer is commonly used to achieve tap switching automatically during the test to improve the efficiency.

Meanwhile, the Y/Δ winding transformer can be used to simulate the voltage and phase transformation being equivalent to all the transformers between the fault point and the EUT.

4.3.4 Grid fault simulator

4.3.4.1 RLC-series emulator

As a configuration of grid fault simulator, the RLC-series emulator is used to create the voltage swell due to connecting the three phases together or connecting the single phase to neutral, via the inductor L, resistor R and capacitor C as shown in the test device layout in Figure 2 and Figure 3.

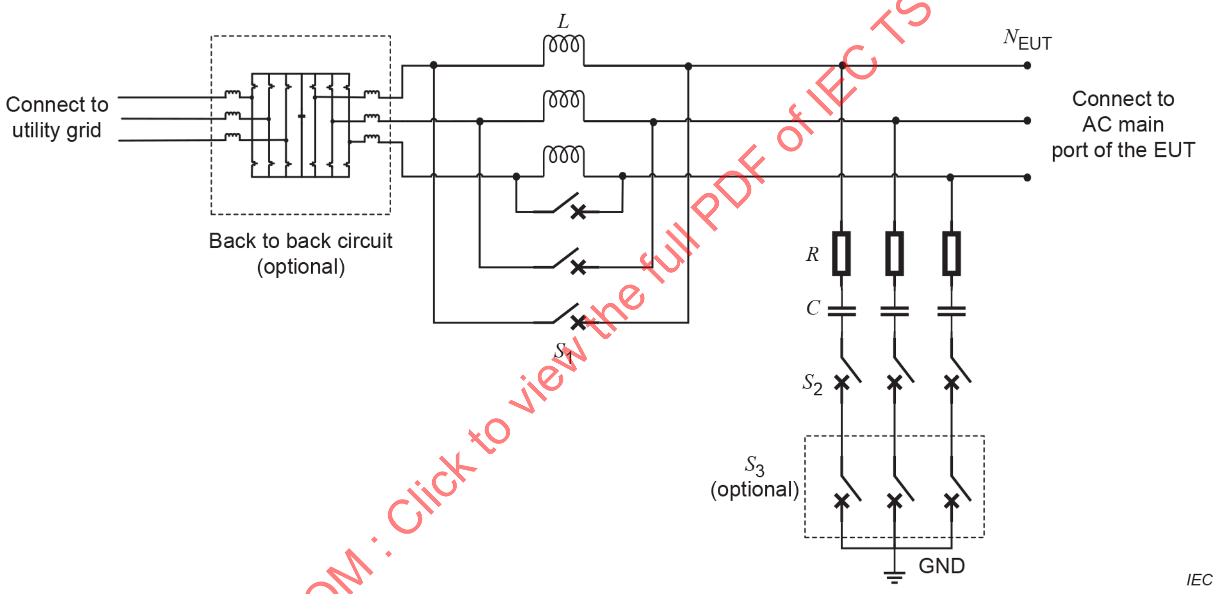


Figure 2 – RLC-series emulator for three-phase EUT

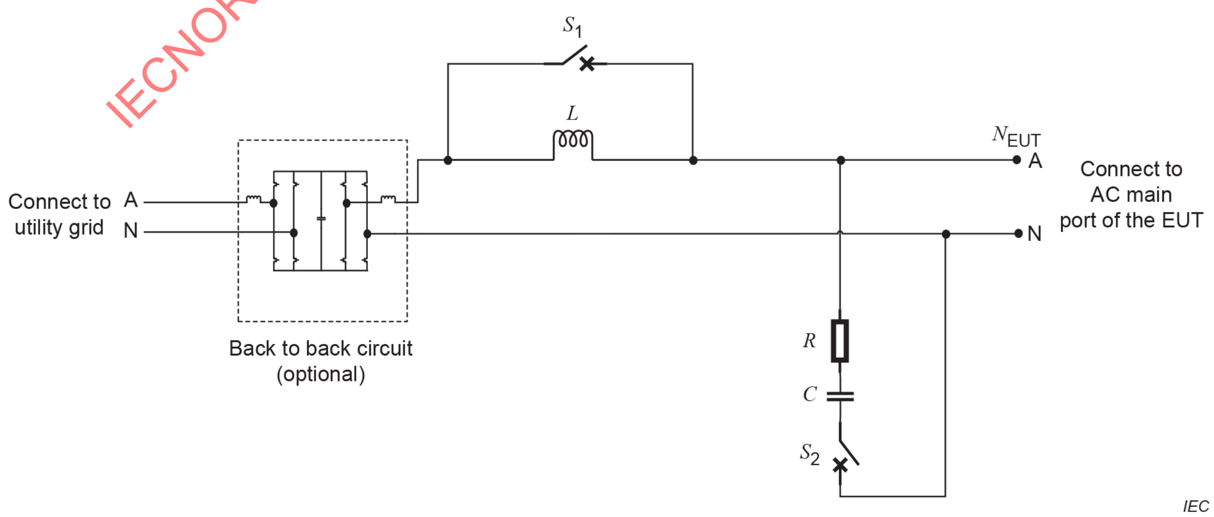


Figure 3 – RLC-series emulator for single-phase EUT

The inductor L is used to limit the effect of the short circuit for the utility grid that powers the test circuit. The sizing of L shall therefore account for all test sequences to be performed and limit the current taken from the grid to values that do not cause an excessive increment of the grid voltage. Considering an acceptable voltage increment of at most 5 % when performing the test, the minimum reactance value of the inductor L shall be at least 20 × Z_{Grid}, where Z_{Grid} is the grid short-circuit impedance of the utility grid.

To ensure that the test is realistic, however, the apparent short-circuit power (S_{EUT}) available at the EUT connection node N_{EUT} should be at least equal to 3 × P_N, where P_N is the rated power of the EUT (minimum value $S_{\text{EUT}} = 3 \times P_N$, recommended $5 \times P_N < S_{\text{EUT}} < 6 \times P_N$). This means that during the OVRT tests, the contribution of current through L from the grid remains dominant compared to the current contributed by the EUT. In this way, the output AC current of the EUT does not create a significant voltage increment for the duration of the test relative to the no-load test.

The two conditions described above define the minimum and maximum limit of L. The two conditions combined also define the limit criteria for the choice of a grid infrastructure suitable for performing the test with the impedance circuit. If the grid infrastructure cannot meet above requirements, an alternative test circuit utilizing a back-to-back converter is allowed, as shown in Figure 2 and Figure 3 and may be added to reduce the grid short-circuit impedance Z_{Grid}.

Generally, the X/R value of inductor L for the RLC-series emulator may be close to the transmission line impedance values for different countries and regions. It is also appropriate that the inductor L should be characterised by an X/R ratio equal to at least 3, in order to reproduce the typical minimum values of X/R found in HV as well as MV power lines.

NOTE 1 X: Equivalent impedance of inductor.

NOTE 2 R: Equivalent resistance of inductor.

A bypass connection (switch S_1) of L is usually used to prevent overheating of the inductor L before and after the execution of each test sequence.

The over voltage event is created by connecting the series resistor R and capacitor C by the switch S_2. The values of Z_1 / (Z_1 + Z_2 + Z_{Grid}) the inductor L or the capacitor C shall be adjustable to meet the required voltage magnitudes. The voltage swell ratio is shown in Formula (1).

$$A_{\text{n}} = \frac{\sqrt{R^2+(\frac{1}{\omega C})^2}}{\sqrt{R^2+(Z_{\text{Grid}}+\omega L-\frac{1}{\omega C})^2}} \qquad (1)$$

where

A_{n} is the ratio of the voltage swell;

R is the parameter of the resistor R;

L is the parameter of the inductor L;

C is the parameter of the capacitor C.

The switch S_2 shall be able to accurately control the time between connection and disconnection of the series resistor R and capacitor C for three-phase tests simultaneously. All switches may be either mechanical circuit breakers or power electronic devices.

With the emulator for three-phase EUT, the switch S_2 shall be able to accurately control the time between connection and disconnection of Z_2 for single-phase, two-phase or three-phase tests. If the phase of switch S_2 cannot be independently controlled, the serial switch S_3 may be used to choose the fault phase. All switches may be either mechanical circuit breakers or power electronic devices.

4.3.4.2 Converter based emulator

The test circuit mentioned in 4.3.4.1 is recommended for simulation of grid faults. However, if the test conditions cannot be met, an alternative test circuit can be used, as shown in Figure 4 and Figure 5.

The test circuit essentially comprises a programmable AC-DC-AC converter with an optional isolation transformer combined optionally with low internal resistance inductor. The converter shall be capable of independently controlling the three phases in terms of amplitude, and the step response time of the voltage change should be less than 10 ms.

The converter should be a bi-directional voltage source, that can absorb all the active power and reactive power generated by the EUT during the test. It is recommended that apparent power of the converter should be greater than P_N, where P_N is the rated power of the EUT.

The inductor L should be adjusted in order to reproduce the ohmic and inductive components of short-circuit impedance that are typical of the utility grid. If the converter is capable of adjusting the output impedance, the inductor can be omitted.

The converter should meet the requirements indicated in Clause 6 of IEC TS 63106-1:2020.

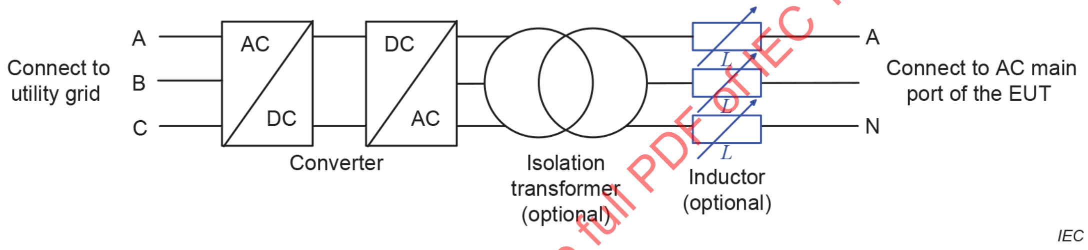


Figure 4 – Converter based emulator for three-phase EUT

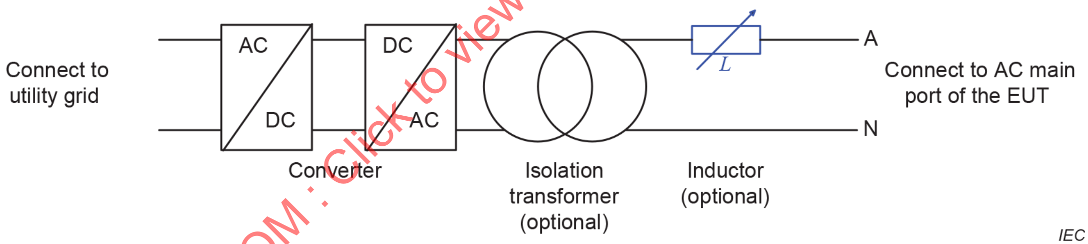


Figure 5 – Converter based emulator for single-phase EUT

5 Test

5.1 Test protocol

The OVRT test protocol is designed to verify that the EUT responds appropriately to temporary over voltage condition (due to grid faults). During the test, the EUT shall demonstrate that it can:

- Appropriately detect the simulated fault.
- Ride through the event and continue operation as specified in the applicable curves.
- Not suffer any damage from the event.

The required levels of active power and reactive power output during the voltage swell period may differ depending on each country local grid codes, both in positive sequence and negative sequence components. The response to the over voltage event specified in Table 2 shall be recorded over the EUT operating period with two output power ranges:

a) between 0,1 P_n and 0,5 P_n;

b) above 0,9 P_n;

and with two fault conditions:

c) three-phase fault;

d) two-phase fault or single-phase fault.

The tests should be carried out at each test point listed in Table 2.

Table 2 – Test specification for OVRT (indicative)

Test sequence[a]	Voltage swell ratio[b]	Fault phase[c]	EUT output conditions[d]	Test points[e]
Test 1#	A_1	three-phase	Full load (above 0,9 P_n)	TP_1
			Partial load (0,1 P_n to 0,5 P_n)	TP_2
		two-phase	Full load (above 0,9 P_n)	TP_3
			Partial load (0,1P_n to 0,5 P_n)	TP_4
		single-phase	Full load (above 0,9 P_n)	TP_5
			Partial load (0,1 P_n to 0,5 P_n)	TP_6
	…	three-phase	Full load (above 0,9 P_n)	……
			Partial load (0,1P_n to 0,5 P_n)	
		two-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
		single-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
	A_n	three-phase	Full load (above 0,9 P	
			Partial load (0,1 P_n to 0,5 P_n)	
		two-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
		single-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
Test 2#	A_1	three-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
		two-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 $P_n$to 0,5 P_n)	
		single-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
	…	three-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
		two-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
		single-phase	Full load (above 0,9 P_n)	
			Partial load (0,1 P_n to 0,5 P_n)	
	A_n	three-phase	Full load (above 0,9 P_n)	TP_{M-5}
			Partial load (0,1 P_n to 0,5 P_n)	TP_{M-4}
		two-phase	Full load (above 0,9 P_n)	TP_{M-3}
			Partial load (0,1 P_n to 0,5 P_n)	TP_{M-2}
		single-phase	Full load (above 0,9 P_n)	TP_{M-1}
			Partial load (0,1 P_n to 0,5 P_n)	TP_M

[a] Test 2# or more consecutive fault test maybe required in some countries or regions. For device under test not being required for second fault test, above testing points can be omitted.

[b] Voltage swell is the temporary voltage during OVRT testing period which can be decided according to the requirement specified by different countries or regions (See Annex A for voltage swell ratio calculation)

[c] Fault phase can be decided according to the requirement specified by different countries or regions; the value of two-phase voltages should be line-to-line voltage.

[d] The test should be carried out under specified K-factor provided by manufacturer meeting additional requirements imposed by national standards and/or local codes.

[e] The number of test points TP_M is equal to the multiplication of the selected voltage swell ratios A_n and the selected fault phases.

5.2 Test curve

The OVRT response characteristic shall meet the requirements of the OVRT curve specified by different countries and regions as needed (see also Annex B). An example OVRT curve is shown in Figure 6.

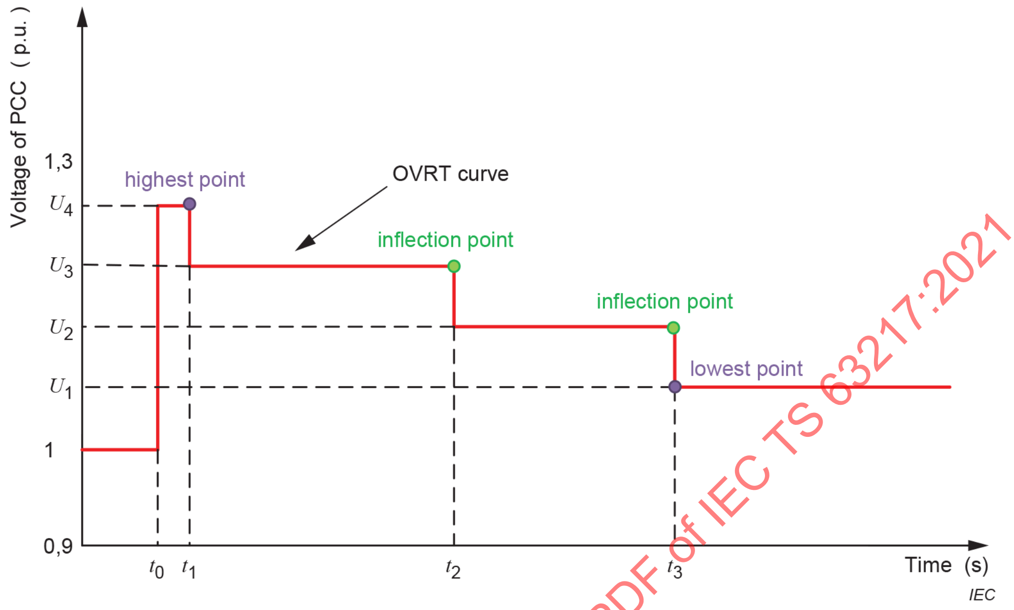


Figure 6 – OVRT curve example

The example curve shows that the EUT should keep operating during the voltage at the point of connection or generator terminal remains below the OVRT curve. Specially, the EUT should keep operating for (t_1- t_0) seconds without disconnecting from the grid when the interconnection voltage swells up to U_4; for (t_2- t_0) seconds when the voltage rises up to U_3; and for (t_3- t_0) seconds when the voltage swells up to U_2. The EUT may disconnect from the grid when the voltage or time over the OVRT curve.

The example shows three types of points on the OVRT curve: the highest point, the lowest point and the inflection point. Tests shall be carried out at each of the above types of point.

5.3 Test procedure

5.3.1 Pre-test

Prior to the fault simulation tests, the EUT should run in normal operating mode. The selected OVRT curve should be used to identify voltage swell points, including the highest point, the lowest point and the inflection point in the curve. Selection of the voltage swell time should follow the requirement applicable country or region.

5.3.2 No-load test

Prior to the load test, adjust the fault emulator to simulate symmetrical and asymmetrical voltage swells without EUT connection, and validate that the measured results are as intended. This step ensures that the amplitude and the duration of voltage swell can match the requirements in Figure 7.

5.3.3 Tolerance

The tolerance for voltage swell and duration during the non-load test shall meet the requirement of Figure 7, based on the requirement of IEC 61400-21-1:2019.

The tolerance for voltage magnitude is ±5 % of rated voltage for the period and during the voltage swell. The tolerance for voltage magnitude is ±10 % of rated voltage during the period after the voltage is recovered. The tolerance shall be measured between 0 and +5 % of rated voltage for the lowest point and the inflection point under no-load tests, and the tolerance shall be measured between -5 % and 0 of rated voltage for the highest point under no-load tests.

The duration of each voltage swell is determined according to the requirements of the applicable OVRT curve. The tolerance range for voltage changing time prefers 20 ms.

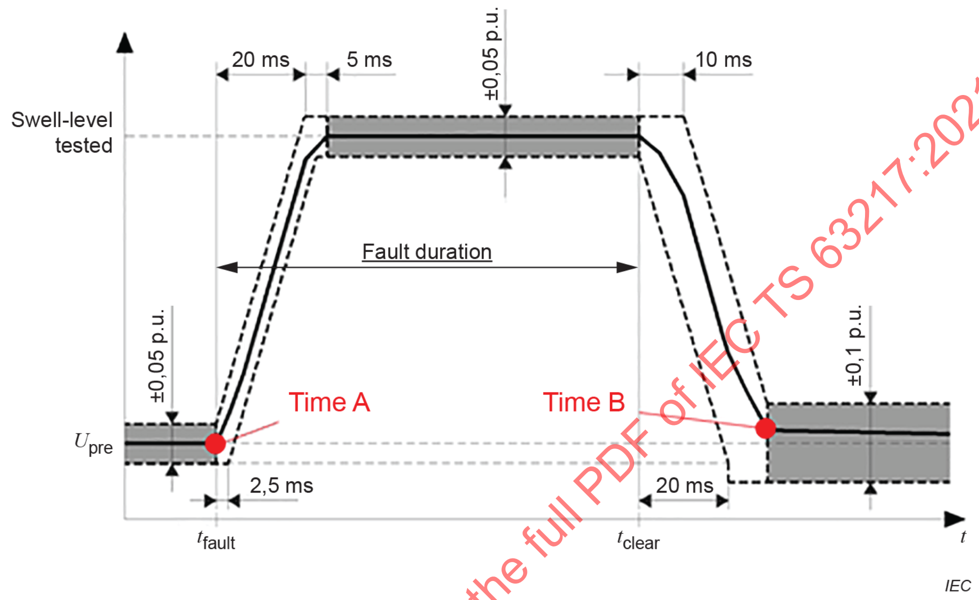


Figure 7 – Tolerance of voltage swell

5.3.4 Load test

Tests under load shall be carried out after the no-load test results successfully meet the performance requirements. The parameters of the grid fault simulator should be consistent with the no-load test.

With the EUT connected to the grid fault simulator device and the PV simulator (or PV array), the output power shall be set to (0,1～0,5)P_n and above 0,9P_n separately. Additional load test at the power levels should be performed as determined by the specified country or regional requirement.

During the OVRT test, MP1, MP2 and MP3 (shown in Figure 1) shall be selected as the test points for measuring and recording the values of voltage and current.

The waveform and data of the measured voltage and current at the measuring points shall be recorded by the data acquisition device from prior to the voltage swell (time A) to after the subsequent voltage swell (time B).

For time A and time B, specific data should be determined by different countries or regions.

6 Assessment criteria

The various assessment criteria are determined by the requirements of different countries or regions. The characteristics and performance criteria for utilization are shown in Annex A and Annex B, and can be referenced by a local user.

Annex A
(informative)

Determination of critical performance values in OVRT testing

A.1 General

This Annex provides suggested methods for determining several of the critical performance values in OVRT testing. Different countries or regions may choose alternate methods according to the requirements of their standards.

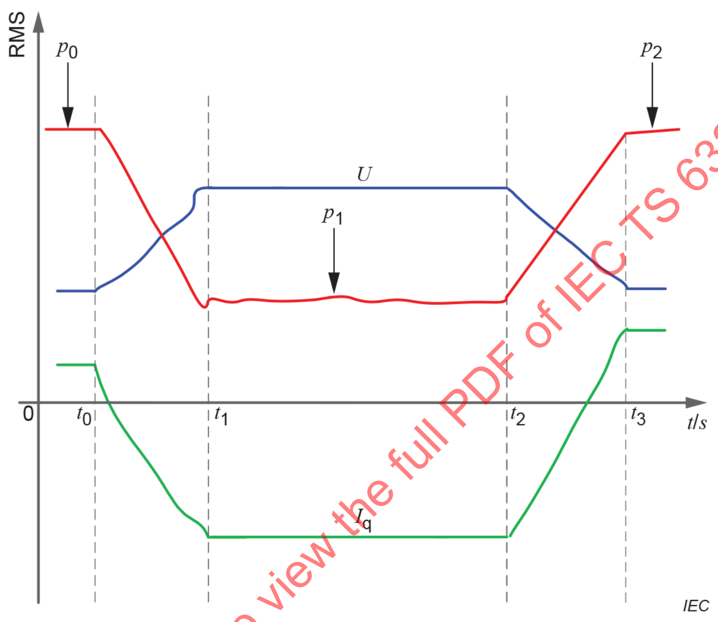


Figure A.1 – Critical performance values in OVRT testing

A.2 Ride-through time

Over the voltage swell period, the EUT shall meet the ride-through time requirements corresponding with the applicable voltage swell. This is shown as the time between t_1 and t_2 in Figure A.1. These requirements will differ depending on countries or regions, however, the OVRT performance should meet or exceed the most demanding requirements for the specified region.

OVRT functions tested successfully according to specific ride-through requirements should only be applied in corresponding countries and regions where those requirements are applicable.

A.3 Voltage swell ratio

As the voltage of the test circuit may deviate from the nominal voltage of system, the rated voltage of the EUT should be used as the reference voltage for calculations of the voltage swell ratio, as shown in Formula (A.1). As such, it is not recommended to use the value of the actual voltage measured prior to the swell test to calculate voltage swell ratio.

$$A_n = \frac{U_{swell}}{U_n} \tag{A.1}$$

where