(F. No.223/35/2018-R&D Coord.)

Ministry of New and Renewable Energy

Block 14, CGO Complex
Lodi Road, New Delhi-110003.

21/4/2020

Subject: Draft Standard on "Technical requirements for Photovoltaic Grid Tie Inverters to be connected to the Utility Grid in India".

The Ministry of New and Renewable Energy(MNRE) is implementing the Quality Control SPV Systems, Components and Devices Order 2017 (under Compulsory Registration Scheme of BIS), which includes SPV Modules, Solar Inverters and Battery Storage used in solar power projects. These products are required to conform to specified Indian Standards/corresponding IEC Standards. In the case of inverters, 2 standards have been specified for quality control. These two standards cover safety requirements as per IS 16221-Part II and islanding prevention measures tests for utility inter-connected photovoltaic inverters as per IS 16169. Both the standards are adopted from IEC.

2. In order to ensure the quality and reliability, it's important that the inverters have to be tested for safety, efficiency, environmental tests and grid inter-connection aspects. In this context, relevant IS/IEC Standards covering safety, efficiency, environmental and islanding prevention measures tests for Utility-Interconnected Photovoltaic Inverters have been perused. Further, in order to make the process of testing simple and consistent, a view has been taken to develop an inclusive standard for Photovoltaic Grid Tie Inverters for complete performance evaluation for grid interactive applications for quality and reliability assurance in Indian conditions.

3. Accordingly, a draft standard titled " **Technical requirements for Solar Photovoltaics Grid Tie inverters"** has been prepared in-consultation with experts from inverter test labs, inverter industry and experts from IITs, and the same is enclosed for inputs/comments of related stakeholders. You are requested to please provide your comments/inputs to this Ministry positively by **30/4/2020** at the following address.

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To

All stakeholders

Ministry of New and Renewable Energy
(Standards & Quality Control Division)

Draft Standard on Technical requirements for

Photovoltaic Grid Tie Inverters

to be connected to the Utility Grid in India

21th April 2020

1 Overview

This standard provides interconnection technical specifications and requirements along with environmental test specifications and requirements applicable for Utility Interconnected Inverters used in Photovoltaic Power Systems.

2 Scope and object

The purpose of this standard is to lay down requirements for interconnection of PV systems/inverters to the utility distribution system, and to provide a test procedure to evaluate utility-interconnected photovoltaic (PV) power systems operating in parallel with the utility and utilizing static (solid-state) non-islanding inverters for the conversion of DC to AC.

This standard applies to interconnection with the low-voltage and medium-voltage utility distribution system.

3 Normative references

The following referenced documents are indispensable for the application of this document.
For dated references, only the edition cited applies.

Requirement of the latest edition of the referenced document (including any amendments) applies.

IS 16221-Part2: Safety of Power Converters for Use in Photovoltaic Power Systems: Particular Requirements for Inverters
IS 16169/ IEC 62116: Utility-Interconnected Photovoltaic Inverters – Test Procedure of Islanding Prevention Measures
IS/IEC 61683: Photovoltaic systems – Power conditioners – Procedure for measuring efficiency
IEC 60068-2-1: Environmental testing – Part 2-1: Tests – Test A: Cold
IEC 60068-2-2: Environmental testing – Part 2-2: Tests – Test B: Dry heat
IEC 60068-2-78: Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state
IEC 61000-3-2: Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions (equipment input current ≤16 A per phase)
IEC 61000-3-3: Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤16 A per phase and not subject to conditional connection
IEC 61000-3-11: Electromagnetic compatibility (EMC) – Part 3-11: Limits – Limitation of voltage changes,
voltage fluctuations and flicker in public low-voltage supply systems – Equipment with rated current ≤75 A and subject to conditional connection
IEC 61000-3-12: Electromagnetic compatibility (EMC) – Part 3-12: Limits – Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and ≤75 A per Phase
IEC/TS 61000-3-5: Electromagnetic compatibility (EMC) – Part 3-5: Limits – Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 75 A

4 Terms and definitions

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

4.1 power factor
power factor (*PF*) is calculated by dividing the kilowatt (kW) by the square root of the sum of the squares of the kilowatt and the kilovar (kVAR).

Power factor (*PF*)

where P is the power in kW and Q is the reactive power in kVAR.

4.2 direct current (DC) interface
connections between the PV array and the input of the inverter.

4.3 electric utility
As used in this standard, an organization responsible for the operation of an electric supply, distribution, and /or transmission system

4.4 safety disconnect control and monitoring subsystem
subsystem that monitors utility grid conditions and removes the AC output of the inverter for out of bounds conditions

4.5 total harmonic distortion (current)
In this standard, the total harmonic current distortion is expressed as a percentage and defined as:

x 100%

where
i_1 is the r.m.s. fundamental full rated output current of the inverter
i_n is the r.m.s. harmonic current of order n

Note: This definition is referred to in some standards (e.g. 1547-2018) as "Total rated current distortion" (TRD)

4.6 photovoltaic system
PV system- a system comprises all inverters (one or multiple) and associated BOS (Balance-Of-System components) and arrays with one point of common coupling to the utility system

4.7 Inverter
A static power conversion device that converts DC electricity into AC electricity.

4.8 Anti-islanding inverter

inverter that will cease to energize a utility system that is out of the normal operation specifications for voltage and/or frequency for more than a specified amount of time

4.9 Utility system

The electrical generation, distribution, and /or transmission system that the PV system is interconnected with.

4.10 Abbreviations and Acronyms

AC	Alternating Current
BIS	Bureau of Indian Standards
CEA	Central Electricity Authority India
DC	Direct Current
HVRT	High Voltage Ride Through
Hz	Hertz (unit of Frequency)
IEC	International Electrotechnical Commission
IS	Indian Standard
ISO	International Organization for Standardization
LV	Low Voltage
LVRT	Low Voltage Ride Through
MNRE	Ministry of New and Renewable Energy
Pn	Nominal Active Power
PV	Photovoltaic
RMS	Root Mean Square
THD	Total Harmonic Distortion
Un	Nominal Voltage

5 Type Tests

5.1 Test conditions

Operating voltage range shall be single phase 240V +10% , -15%(as per CEA)
Operating frequency range – 50Hz +/- 2% (as per CEA).

Unless otherwise specified, all tests shall be carried out under the nominal input and

output power conditions at room ambient between 25°C ± 5°C.
The equipment shall be connected and configured in accordance with the manufacturer's instruction, where the outcome of testing could be affected.

5.2 Samples
The sequence of tests is optional unless otherwise specified in this standard.
(Note: The MNRE series guidelines shall be referred to for selecting the samples from a single family of inverters)

5.3 Grid Interconnection Tests
5.3.1 DC Injection
The PV system shall not inject DC current greater than 0.5 % of the continuous maximum rated inverter output current, into the utility interface, when tested at 25%, 50%, 75% and 100% of rated output power.

The requirement is not applicable for an inverter that interconnects through a line frequency isolation transformer located between the output of the inverter and the utility system.

5.3.2 Harmonics
The inverter output total harmonic current distortion shall be not more than 5 % at rated inverter output. The inverter shall be tested as per IEC 61000-3-2 or IEC 61000-3-12.

Each individual harmonic shall not exceed the applicable limit in Table 1. Limits shown are percentage of inverter full rated current. The measurement shall be performed at 25%, 50%, 75% and 100% of rated output power up to and including 50th order.

Table 1 Current distortion limits

Odd harmonics	**Distortion limit**
3rd through 9th	Less than 4.0 %
11th through 15th	Less than 2.0 %
17th through 21st	Less than 1.5 %
23rd through 33rd	Less than 0.6 %
35th through 49th	Less than 0.3%

Even harmonics	**Distortion limit**
2nd through 8th	Less than 1.0 %
10th through 14th	Less than 0.5 %
16th through 20th	Less than 0.38%
22nd through 32nd	Less than 0.15%
34th through 50th	Less than 0.08%

(Note: CEA document is referring to IEEE 519 standard; but BIS Recognized labs or ISO 17025 labs in India are not accredited to conduct Harmonic test as per this standard; hence suggest to move away from IEEE standard and refer to IEC standard).

5.3.3 Flicker

Flicker is the subjective impression of fluctuating luminance caused by voltage fluctuation. Flicker severity is measured and calculated with respect to both short-term and long-term effects.

5.3.3.1 For inverters connecting to the utility system, the inverter shall comply with the limits in the applicable standard as follows:

- IEC 61000-3-3 for inverters with rated current ≤16 A per phase and not subject to conditional connection
- IEC 61000-3-11 for inverters with rated current ≤75 A per phase and subject to conditional connection
- IEC 61000-3-5 for inverters with rated current >75A per phase and subject to conditional connection

Note: The term "conditional connection" refers to a requirement that the impedance of the utility system at the point of connection must be lower than a reference impedance calculated such that the flicker emissions limits are complied with; refer to the above standards for details

5.3.3.2 For inverters connecting to the utility system at Medium Voltage: The inverter shall be tested in accordance with IEC 61000-3-7, and the flicker coefficients (dc%, dmax%, Pst, Plt) shall be reported in the documentation for the inverter, for use in the interconnection assessment

5.3.4 Protection against abnormal voltage and frequency

NOTE Because of its integrated nature, the inverter is only required to be totally disconnected from the utility for service or maintenance. At all other times, whether the inverter is transferring PV energy to the utility or not, the control circuits remain connected to the utility to monitor utility conditions. The phrase, "cease to energize" is used throughout this document to indicate that the inverter is no longer exporting energy to the utility system, but does not become totally disconnected it, when a trip function occurs, such as an overvoltage trip. The inverter can be completely disconnected from the utility for inverter maintenance by opening a utility AC-disconnect switch.

5.3.4.1 Protection against abnormal voltage

The inverter shall cease to energize the utility system in response to abnormal voltage at the inverter terminals, in the time required as specified in Table 2. The system shall respond to RMS voltage on any phase or combination of phases as per the settings given in Table 2.

Table 2 Response to abnormal voltages for voltage interconnection application

Voltage (%Un)	**Mode of operation**	**Ride through until**	**Maximum response time***
V < 50%Un	LVRT	1.7 s	1.8 s
50%Un ≤ V < 85%Un		3 s	3.1 s
85%Un≤ V ≤ 110%Un	Continuous operation		N/A
110%Un < V ≤ 120% Un	HVRT	2 s	2.1 s
120%Un < V ≤ 130% Un		0.2 s	0.3 s
V > 130%Un		-	0.05 s **

*Response time refers to the time between the abnormal condition occurring and the inverter ceasing to energize the utility line. The PV system control circuits shall remain connected to the utility to allow sensing of utility electrical conditions for use by the "reconnect" feature.
** Disconnection allowed from the utility line

NOTE TO BIS and CEA: CEA Technical Standards for Connectivity to the Grid, does not mention any ride through and trip requirements for voltage less than 110% in CEA:2019 version document B(7). Hence, it should be included here.

The purpose of the allowed time delay is to ride through short-term disturbances to avoid excessive nuisance tripping. The inverter does not have to cease to energize if the utility interface voltage returns to the normal utility continuous operation condition within the specified ride through time.

5.3.4.2 Protection against abnormal frequency

When the utility frequency deviates outside the specified conditions the non-islanding inverter shall cease to energize the utility interface. The inverter does not have to cease to energize if the frequency returns to the normal utility continuous operation condition within the specified trip time.

When the utility frequency is outside the continuous operation range of 47.5Hz and 52 Hz, the non-islanding inverter shall cease to energize the utility interface within 0.2 s. The purpose of the allowed range and time delay is to allow continued operation for short-term disturbances and to avoid excessive nuisance tripping in weak-utility system conditions.

5.3.5 Response to utility recovery

Following an abnormal voltage or frequency event that has caused the photovoltaic system to cease to energize, the photovoltaic system shall not energize the utility line for an adjustable time delay between 20 seconds and 300 seconds after the utility service voltage and frequency have recovered to within the following specified ranges**.**

- Voltage between 85% Un and 110% Un
- Frequency between 49.5Hz to 50.5Hz

5.3.6 Protection against unintentional islanding

The PV system shall cease to energize the utility line within 2 s of formation of an island. Anti-islanding protection shall be verified by testing as per the requirements of IEC 16169.

6 Grid management

6.1 Ride Through Characteristic

The PV systems connected to the LV and MV lines shall be capable of remaining connected to the grid during Low Voltage and High Voltage conditions as explained in Clauses 6.1.1 and 6.1.2 below.

6.1.1 Low Voltage Ride Through (LVRT)

The PV systems shall remain connected to the grid when the voltage at the interconnection point on any or all phases dips up to the levels depicted by the thick lines in the following curve in **Figure 1 LVRT and HVRT regions**.

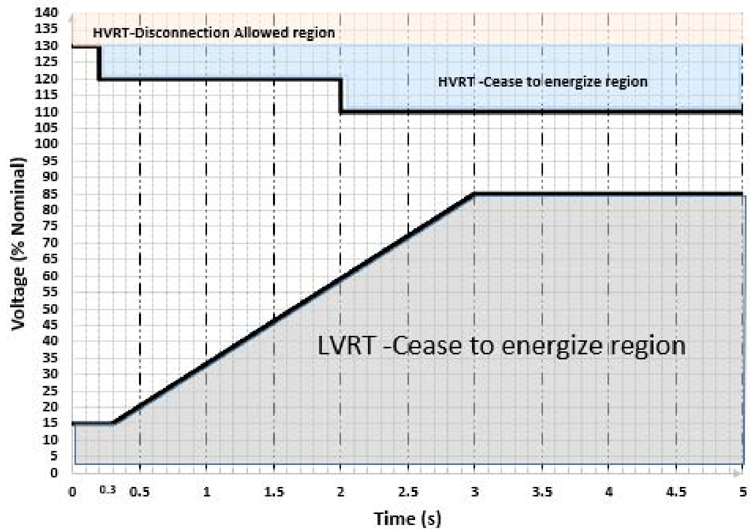

Figure 1 LVRT and HVRT regions

Provided that during the voltage dip, the supply of reactive power has first priority, while the supply of active power has second priority and the active power preferably be maintained during voltage drops, provided, a reduction in active power within the plant's design specifications is acceptable and active power be restored to at least 90% of the pre-fault level within 1 sec of restoration of voltage

Note: Voltage dip tolerance ±5%Un; Test at no load, 30%Pn and 100%Pn.

Single Phase inverter applicability may be debated for LVRT/HVRT

6.1.2 High Voltage Ride Through (HVRT)

The PV systems shall remain connected to the grid when the voltage at the interconnection point on any or all phases increases up to the levels depicted by the thick lines in the following curve in **Figure 1 LVRT and HVRT regions**. Inverter can disconnect from the utility for the voltages in the region HVRT-disconnection allowed region as per **Figure 1 LVRT and HVRT regions**.

Note: Voltage dip tolerance ±5%Un; Test at no load, 30%Pn and 100%Pn.

6.2 Active Power Control

6.2.1 Control through external command

The PV system/inverter shall be able to reduce or increase its active power output, within its ratings, by means of external command.

If the produced power is already below the request, the power production shall not

change.
Conversely, the required power production shall be reached within 1 minute from the receiving of the external command, with a tolerance of ± 5% Pn.
In case of a request for reduction to a power below 10% Pn, the disconnection of the inverter from the network is permitted.

For the compliance of the above requirement, the tests need to be performed from 100% Pn until 0%Pn is reached in step reduction of 10% using the external command.
The active power shall be measured as 1 minute average after the set point signal has reached the inverter and given 1 minute for the inverter to run the command.
The deviation from the set point in the minute of measurement shall be within ± 5% Pn, to consider the test valid and passed.

The method and means used to give the step point signal externally needs to be documented in the test report. In addition, it will be necessary to report the results on a chart the course of the set -point, the trend of the values of the average power measured, the tolerances on the values of the average power measured with respect to the set-point.

6.2.2 Real power reduction in response to over-frequency

The PV system/inverter (with installed capacity of more than 25 kVA shall reduce real power in response to over-frequency, proportional to the frequency deviation from the nominal frequency as given in **Figure 2 Real power reduction in response to over-frequency curve**.

The decrease in active power generated must occur as soon as the frequency threshold is exceeded. Frequency threshold shall be adjustable from 50.5Hz to 52.0 Hz, with a default setting of 50.6 Hz.

When system frequency exceeds f_{start} (default setting as 50.6Hz), the active power output produced by the inverter shall be reduced by at least 40% of rated power per hertz. If the grid frequency exceeds the over-frequency trip limit of 52.0Hz, it is permitted to disconnect the inverter from the grid honoring the time requirement as per 5.3.4.2.
The inverter shall resume its normal operation by increasing the active power only when the frequency falls below the f_{start}.

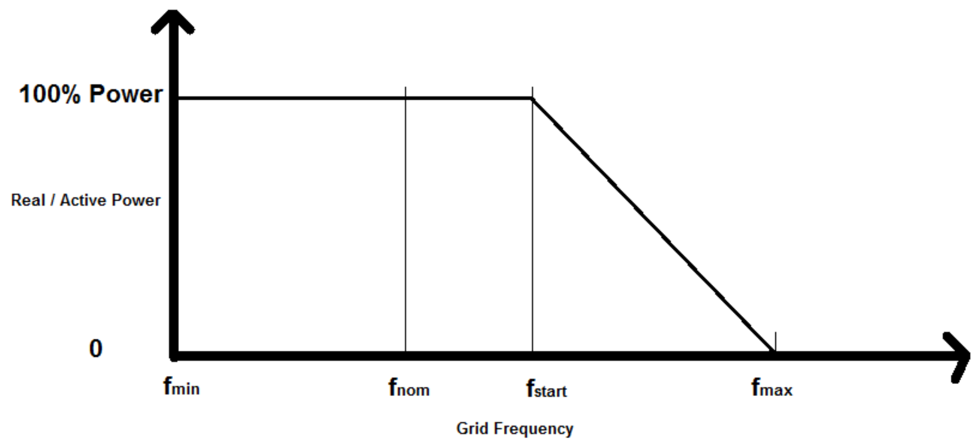

Figure 2 Real power reduction in response to over-frequency curve

f_{nom}: Nominal Frequency
f_{max}: Maximum Over Frequency

Testing shall be performed at 100% and 50% of output power with a minimum of 5 points tested above f_{start} while increasing the frequency.

Active power gradient shall not increase more than 10% per minutes when frequency return to fnom.

6.3 Power factor

6.3.1 Fixed power factor

The inverter shall have a provision to operate at a power factor between 0.8 capacitive and 0.8 inductive with an accuracy of ± 0.01 as per **Figure 3 Reactive power diagram**.

6.4 Fixed reactive power

The inverter shall be capable to produce capacitive or inductive reactive power of maximum 60% of the inverter apparent power as per **Figure 3 Reactive power diagram**.

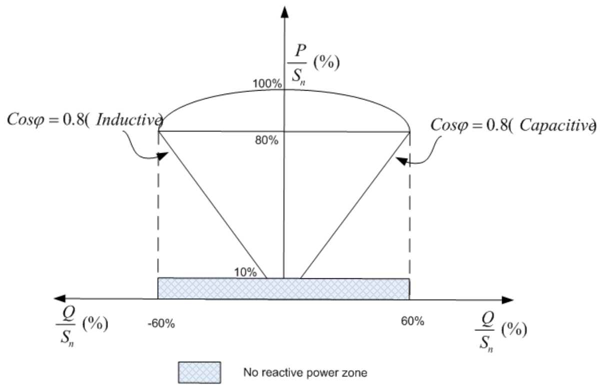

Figure 3 Reactive power diagram

P: Active power; Q: Reactive Power; $S_{n:}$ Maximum apparent Power of the inverter

7 Safety and Environmental Tests

i) Safety

The inverter shall be evaluated and tested for safety to ensure protection against electric shock, energy, fire, mechanical and other hazards as per IS16221-Part 2.

ii) Environmental

The inverters shall be subjected to the environmental tests below in accordance with the IEC 60068-2 series of standards as follows:

Unless otherwise stated all inverter shall be subjected to the environmental test conditions in nominal operating conditions for at least for the minimum severity levels given along with each standard as given below.

- Environmental testing –The inverter shall be operated in nominal operating condition in an ambient of -25°C for a minimum of 16hours for carrying out Environmental testing as per IEC 60068-2-1.

- Environmental testing The inverter shall be operated in nominal operating condition in an ambient of +60°C for a minimum of 16hours as per IEC 60068-2-2:.

- Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, steady state

  The inverter shall be operated in nominal operating condition in an ambient of 50°C ± 2°C with relative humidity of 93% ± 3% for a minimum time duration of

48hours. as per IEC 60068-2-78:

After completing each of the above-mentioned environmental tests, the inverter shall function as intended.

8 Efficiency Tests

Conversion Efficiency: The inverters shall be tested according to IEC 61683 to evaluate the conversion efficiency with following deviations.

- It is not necessary to calculate the efficiency at 5% Inverter power Level.
- The weighting factors given in the below table shall be used for calculating the weighted Efficiency between 10% Inverter power Level and 100% Power level.

Table 3 Weighting factors for calculating Weighted Efficiency

Inverter Power Level	Weighting Factor
10%	0.06
20%	0.13
30%	0.10
50%	0.48
75%	0.00
100%	0.20

The weighted efficiency shall be stated in the documentation for the inverter.
Note: The values of weighting factors provided here is for reference only as per Euro efficiency. These values for India shall be vetted by MNRE and NISE, and if necessary shall be replaced by values relevant to Indian Solar Irradiance conditions.

9 Routine Tests

The following routine test shall be performed by the manufacturer on 100% of production inverters and a test report shall be included with each inverter.

- Protection against abnormal voltage (see 9.1)

- Protection against abnormal frequency (see 9.2)

- Response to utility recovery (see 9.3)

These tests assume that the equipment has met the applicable requirements of this standard and may be conducted as a factory test or performed as part of a commissioning test.

For any of the tests to be conducted as per this clause, function settings need be recorded only once. The report shall provide a list of final settings.

9.1 Protection against abnormal voltage

9.1.1 Purpose

The purpose of this test is to verify the response of the inverter responds to abnormal voltage conditions as required. Trip setting shall be as specified by the manufacturer

9.1.2 Procedure

a) Connect the inverter according to the instructions and specifications provided by the manufacturer.
b) Verify all parameters are at nominal operating conditions for the inverter.
c) Set the inverter to the manufacturer's trip voltage and time settings as applicable. Verify that all of the other settings are at their factory set points.
d) Record applicable settings.
e) Select one of the undervoltage or overvoltage protective functions for test.
f) Adjust the voltage to a point at least twice the manufacturer's stated accuracy outside the abnormal voltage trip setting. Record the rms voltage magnitude and trip time.
g) For multiphase units perform this test on each phase, adjusting one phase at a time.
h) Repeat steps e) through g) for all of the undervoltage and overvoltage protective functions.

9.1.3 Criteria

The test results are acceptable if the inverter trips in the ranges specified by the manufacturer.

9.2 Protection against abnormal frequency

9.2.1 Purpose

The purpose of this test is to verify the response of the inverter to abnormal frequency conditions as required. Trip setting shall be as specified by the manufacturer.

9.2.2 Procedure

a) Connect the inverter according to the instructions and specifications provided by the manufacturer.
b) Verify all parameters are at nominal operating conditions for the inverter.
c) Set the inverter to the manufacturer's trip frequency and time settings as applicable. Verify that all of the other settings are at their factory set points.
d) Record applicable settings.
e) Select one of the underfrequency or overfrequency protective functions for test.
f) Adjust the frequency to a point at least twice the manufacturer's stated accuracy outside the abnormal frequency trip setting. Record the frequency and trip time.
g) Repeat steps e) through f) for all of the underfrequency and overfrequency protective functions.

9.2.3 Criteria
The test results are acceptable if the inverter trips in the ranges specified by the manufacturer.

9.3 Response to utility recovery
9.3.1 Purpose
The purpose of this test is to verify the functionality of the inverter reconnection time following a trip event.

9.3.2 Procedure

a) Connect the inverter according to the instructions and specifications provided by the manufacturer.
b) Verify all parameters are at nominal voltage and frequency. Record applicable settings.
c) Verify that the inverter is operating properly when connected to the gird or simulated source.
e) Disconnect the gird or simulated source from the inverter.
f) Reapply the gird or simulated source and record all required parameters including the time taken by the inverter to reconnect to the grid or simulated source.

9.3.3 Criteria
The test results are acceptable if the inverter reconnects with the gird or simulated source as specified by the manufacturer.

APPENDIX A - GENERAL TEST AND REPORTING REQUIREMENTS

A1 General
This Appendix specifies requirements for the configuration of the equipment under test, the real test grid or simulated test grid and the reporting of results in test report.

A2 Test Conditions
Unless otherwise specified by the test procedure, the testing conditions for each test shall be such that-

- the average r.m.s. current on each phase is within ±5% of the intended test point; and
- the average r.m.s. voltage on each phase is within ±5% of the grid test voltage.

In the case of a three-phase supply, the angle between the fundamental voltages of each pair of phases shall be maintained at 120 ±1.5°. The average r.m.s. voltages between each pair of phases shall be maintained within ±1%.

The grid test voltage shall be 230 V a.c. phase to neutral 50 ±0.1 Hz, unless otherwise specified.

A3 Inverter Set- Up

Each inverter that is to be tested shall have its internal settings and configurations set to the default set-points required by this Standard, as they would be for operation in an installation.

For inverters that have configurations or functionality that can be enabled or disabled, and which may have an impact on the test results, the test shall be either repeated with the valid configurations enabled and disabled or be carried out with the least favorable settings.

Before commencement of the test, all model information and specific information concerning the version of software, firmware and hardware used by the inverter shall be recorded. This information shall be provided in the test report.

A4 Grid Source

Either a real grid or a simulated test grid shall be used in the testing.

If a grid simulator is used, it shall be rated for at least 150% of the rated current of the unit under test.

During the tests, the steady-state voltage of the real or simulated test grid shall not vary by more than ±1% of the nominal voltage. The grid test voltage shall be set as required by each test.

For tests requiring step changes in voltage and/or frequency, the simulated test grid shall be at least capable of being stepped at 0.5 times the smallest step required for testing, to determine the set- points with required accuracy.

A5 Test Set-Up

The inverter shall be connected into a test circuit equivalent to that shown in Figure 4 General Test Setup.

NOTE: This test circuit applies to a single-phase system. To test a three-phase system, an equivalent three-phase circuit is required.

Figure 4 General Test Setup

APPENDIX B - DC INJECTION MEASUREMENT

B1 General

The purpose of this test is to verify that the inverter complies with the DC current injection

limit requirement specified in section 5.3 when it connects to the grid. This test is required for inverters that do not incorporate a mains frequency isolating transformer either internally or

externally.

The inverter shall be placed in a test circuit equivalent to that shown in Figure 4 General Test Setup. For three-phase systems, current shall be measured in each phase conductor. For single-phase inverters, either the active or neutral current may be measured.

If used, the simulated test grid shall have negligible DC offset before the test commences.

B2 Test Procedure

The procedure shall be as follows:

- Operate the inverter at 25% of its rated current and at rated power factor. The inverter shall operate for at least 5 min prior to taking any test measurements (or until the inverter temperature stabilizes). The inverter shall operate at the specified current for the period of the measurement
- At the inverter output, measure the r.m.s. voltage, r.m.s. current, and d.c. component (frequency less than 1 Hz) of current on all phases. The average value of 180 consecutive readings of the d.c. component with a measurement period of 1 s for each reading shall be calculated. The inverter passes the requirement of this Standard if the average of the 180 consecutive readings is below the limit specified in section 5.3. For each 1s sample, the absolute value (i.e. unsigned value) shall be used to calculate the 180 s average.
- Repeat Steps a) and b) with the inverter operating at 50%, 75% and 100% of its rated current.
- Divide the calculated average values for the magnitude of the DC component of current by the rated current of the inverter and derive the value of the DC current injection as a percentage. This shall be done for 4 test points (25%, 50%, 75% and 100%) and for each phase and/or neutral measurement. Record the final calculated values as the percentage of DC current injection for each phase.

B3 D.C. Current Limits

All DC current injection levels, calculated as percentages, shall be within the limit specified in section 5.3.

The resolution of the DC component measurement shall be 1 mA or 5% of the applicable limit, whichever is greater, as specified in section 5.3.

APPENDIX C - PROTECTION AGAINST ABNORMAL VOLTAGE AND FREQUENCY

C1 General

The purpose of this test is to verify the voltage and frequency limits for connection and reconnection and the ramp rate upon reconnection as per the requirement specified in section 5.3.4 and 5.3.5.

The inverter shall be placed in a test circuit equivalent to that shown in Figure 4 General Test Setup. For three-phase systems, the abnormal voltage test needs to be conducted on all phases together and on individual phases. The abnormal frequency test needs to be conducted only on all phases together.

C2 Test Procedure

C2.1 Measuring the trip threshold for the Over Voltage and Over Frequency

- The variable grid supply shall be set so that the voltage at the a.c terminals of the device under test equals the nominal grid voltage and frequency. The voltage at the a.c. terminals shall be maintained till the inverter connects to the grid and start exporting the power.
- Start the power analyzer data recording at a recording window of 200ms.
- Change the grid voltage equal to 0.9 of the thresholds set for voltage measurement.
- Gradually increase the grid voltage using the variable grid supply at 1.5Volts per second till the inverter disconnects from grid.
- Stop the recording of the power data and locate the gird voltage value when the inverter got disconnected from the grid.
- Repeat the above steps for the frequency parameter except for the following:

- Maintain the grid voltage at nominal value during the complete procedure.
- In step c) set the gird frequency as 0.99 of the frequency thresholds.
- In step d) Increase the grid frequency at 10mHz per second till the inverter disconnect and record the value of the frequency at which the inverter disconnected from grid.

- The above steps are repeated for 3 times and the results are to be recorded.

C2.2 Measuring the trip time and reconnection for the Over Voltage and Over Frequency

- Set the grid voltage equal to 0.9 of the thresholds set for voltage measurement.
- Increase the grid voltage instantaneously (i.e. step function) to the trip threshold plus 1% of nominal.
- Measure the time required by the inverter to disconnect from the grid from the instance at which the step function has initiated using an oscilloscope.
- The variable grid voltage shall be adjusted to return the voltage at the a.c terminal of the device to 110% of Un.
- The reconnection time taken for the device to reconnect to the variable a.c. supply shall be recorded.
- Repeat the above steps for the frequency parameter except for the following:
    - Maintain the grid voltage at nominal value during the complete procedure.
    - In step a) set the gird frequency as 0.99 of the frequency thresholds.
    - In step b) Increase the grid frequency instantaneously (step function) to the trip threshold plus 1% of nominal.
    - In step d) return the frequency at the a.c terminal of the device to 52Hz for recording the reconnection time.
- The above steps are repeated for 3 times and the results are to be recorded.

C2.3 Measuring the trip threshold for the Under Voltage and Under Frequency

- The variable grid supply shall be set so that the voltage at the a.c terminals of the device under test equals the nominal grid voltage and frequency. The voltage at the a.c. terminals shall be maintained till the inverter connects to the grid and start exporting the power.

- Start the power analyzer data recording at a recording window of 200ms.
- Change the grid voltage equal to 1.1 of the thresholds set for voltage measurement.
- Gradually decrease the grid voltage using the variable grid supply at 1.5Volts per second till the inverter disconnects from grid.
- Stop the recording of the power data and locate the gird voltage value when the inverter got disconnected from the grid.
- Repeat the above steps for the frequency parameter except for the following:
    - Maintain the grid voltage at nominal value during the complete procedure.
    - In step c) set the gird frequency as 1.01 of the frequency thresholds.
    - In step d) Decrease the grid frequency at 10mHz per second till the inverter disconnect and record the value of the frequency at which the inverter disconnected from grid.
- The above steps are repeated for 3 times and the results are to be recorded.

C2.4 Measuring the trip time and reconnection for the Under Voltage and Under Frequency

- Set the grid voltage equal to 1.1 of the thresholds set for voltage measurement.
- Decrease the grid voltage instantaneously (i.e. step function) to the trip threshold minus 1% of nominal.
- Measure the time required by the inverter to disconnect from the grid from the instance at which the step function has initiated using an oscilloscope.
- The variable grid voltage shall be adjusted to return the voltage at the a.c terminal of the device to 85% of Un.
- The reconnection time taken for the device to reconnect to the variable a.c. supply shall be recorded.
- Repeat the above steps for the frequency parameter except for the following:
    - Maintain the grid voltage at nominal value during the complete procedure.
    - In step a) set the gird frequency as 1.01 of the frequency thresholds.
    - In step b) Decrease the grid frequency instantaneously (step function) to the trip threshold minus 1% of nominal.

- In step d) return the frequency at the a.c terminal of the device to 47.5Hz for recording the reconnection time.

- The above steps are repeated for 3 times and the results are to be recorded.

C3 Limits

The trip threshold and the trip time for abnormal voltage and frequency shall meet as per the requirement in section 5.3.4
The recovery time by the inverter after an abnormal voltage and/or frequency event shall meet as per the requirement in section 5.3.5

APPENDIX D - RIDE THROUGH CHARACTERISTIC

D1 General

The purpose of this test is to verify the behavior of the unit in response to the sudden low and high voltage characteristics that are outside the normal operation range as per the requirement specified in section 6.1.

The inverter shall be placed in a test circuit equivalent to that shown in Figure 4 General Test Setup.

A current waveform monitoring equipment which can be set to 10K samples/seconds shall be used to capture the various voltage, active current, reactive currents, etc.

Note: During the procedure, the settings of parameters for other functions, or voltage parameters for other voltage regions, shall be set so as not to influence the test results for the operating region being evaluated, or shall be disabled.

In some cases, this may be accomplished by disabling functions or setting the limits to levels outside the test parameters such that they do not interfere with this test.

D2 Test Procedure
D2.1 LVRT
The variable grid simulator is programmed as per the test profiles given in the table below.

The below test conditions need to be performed at both 20% of nominal power and above 90% of nominal power with reactive power set to 0%.

The voltage grid simulator must produce voltage dips for verification as per the below profiles under no-load operating condition when connected with the unit under test.

The Time trend of active power P, Reactive power Q and Phase voltages at each output terminals shall be captured using an appropriate instrument with at least 10k samples/second.

The data capture window shall be 5seconds before the beginning of the voltage transient and ends at least 5seconds after the end of the voltage transient and the restoration of active and reactive power is established.

D2.1.1 LVRT TEST CONDITIONS

Test No.	Dip Depth [p.u]	Duration [ms]	Type	Reactive Power [p.u]	Active Power [p.u]
•	0.15	300	3-phase symmetrical fault	0	1
•	0.15	300	3-phase symmetrical fault	0	0.2
•	0.15	300	2-phase asymmetrical fault	0	1
•	0.15	300	2-phase asymmetrical fault	0	0.2
•	0.15	300	LV 2-phase asymmetrical fault	0	1
•	0.15	300	LV 2-phase asymmetrical fault	0	0.2
•	0.40	1264	3-phase symmetrical fault	0	1
•	0.40	1264	3-phase symmetrical fault	0	0.2
•	0.40	1264	2-phase asymmetrical fault	0	1
•	0.40	1264	2-phase asymmetrical fault	0	0.2
•	0.40	1264	LV 2-phase asymmetrical fault	0	1
•	0.40	1264	LV 2-phase asymmetrical fault	0	0.2
•	0.85	3000	3-phase symmetrical fault	0	1
•	0.85	3000	3-phase symmetrical fault	0	0.2
•	0.85	3000	2-phase asymmetrical fault	0	1
•	0.85	3000	2-phase asymmetrical fault	0	0.2
•	0.85	3000	LV 2-phase asymmetrical fault	0	1
•	0.85	3000	LV 2-phase asymmetrical fault	0	0.2

3-phase symmetrical fault	2-phase asymmetrical fault	LV 2-phase asymmetrical fault

LV 2 Phase asymmetrical fault requirement							
Test No.	U/Unom	Phase-Earth voltages			Phase Angles		
		U_1/U_{1nom}	U_2/U_{2nom}	U_3/U_{3nom}	L1	L2	L3
2-phase asymmetrical fault	0.15 ± 0.05	0.90± 0.05	0.90± 0.05	0.15 ± 0.05	27°	-147°	113°
	0.45 ± 0.05	0.90± 0.05	0.90± 0.05	0.45 ± 0.05	15°	-135°	115°
	0.85 ± 0.05	0.95± 0.05	0.95± 0.05	0.85 ± 0.05	7°	-127°	127°
Normal	1	1	1	1	0°	-120°	120°

D2.2 HVRT

The unit shall be connected to the circuit as per the requirement in D1 above.

Set all the parameters of the input source to the nominal operating conditions for the inverter.

Set and verify all the inverter parameters to the default rated operating conditions and set the output power to the rated maximum power.

Program the voltage magnitude and duration of the step function to the maximum value for the region being tested.

The Time trend of active power P, Reactive power Q and Phase voltages at each output terminals shall be captured using an appropriate instrument with at least 10k samples/second.

The data capture window shall be 5seconds before the beginning of the voltage transient and ends at least 5seconds after the end of the voltage transient and the restoration of active and reactive power is established.

D2.2.1 HVRT TEST CONDITIONS

Test No.	Transient [p.u]	Duration [ms]	Type	Reactive Power [p.u]	Active Power [p.u]
•	1.3	300		0	1
•	1.2	2000		0	1

APPENDIX E - ACTIVE POWER CONTROL

E1 General

The purpose of this test is to verify that the inverter complies with the Active power control specified in section 6.2 when it connects to the grid.

The inverter shall be placed in a test circuit equivalent to that shown in Figure 4 General Test Setup.

E2 Test Procedure

E2.1 Control through external command
The procedure shall be as follows:

- Operate the inverter at 100% of its rated nominal power; Measure and record the output power as 1-minute average.
- After 1 minute of operation, set the power of the inverter to reduce to 90% of rated power using external command.
- The inverter shall be given 1 minute to process the command and after which the active output power shall be measured and recorded (1-minute average)
- Subsequently set another 10% power reduction using the external command until the value of 0% is reached.
- Calculated the deviation of the 1-minute average value from the set point at ach power reduction.

E2.2 Real power reduction in response to over-frequency
The procedure shall be as follows:

The test must be performed in two sequences w.r.t inverter output nominal power levels. Starting from 100% inverter nominal power and starting from 50% inverter nominal power

- Operate the inverter at 100% of its rated nominal power.
- Sweep the grid frequency through the following steps with a dwell time of 2-minutes at each frequency step. (First 1-minute is for the inverter to run the command and stabilize; Second 1-minute for the average measurement of inverter output power)
    - f = 47.51Hz
    - f = 50.20Hz
    - f = 50.40Hz
    - f = 50.60Hz
    - f = 51.99Hz

- After executing step 5, bring the frequency back to nominal value to verify the conditions of gradual power recovery to the initial set output power value.

- The results are recorded in a table and represented on a graph with the expected performance and the measured performance.
- The deviation between the expected and the measured active power values is calculated and verified with the required power reduction gradient.
- Repeat the above steps with the inverter delivering 50% of nominal power.
-

E3 Limits

E3.1 CONTROL THROUGH EXTERNAL COMMAND LIMIT
Deviation from the set point during the minute of measurement must be with in ±5%Pn as per the requirement in section 6.2.1

E3.2 REAL POWER REDUCTION IN RESPONSE TO OVER-FREQUENCY

- Deviation between the expected and the measured active power shall be within a tolerance of ±5%Pn where Pn is the nominal power of the inverter as per the requirement in section 6.2.2; and,
- The inverter has reduced its output power at a rate of 40% of rated power per increase in hertz from the threshold of f_{start}; and,
- the gradual re-store of the supply shall not exceed a maximum positive slope of 10% of the maximum power supplied per minute before the increase in frequency.

APPENDIX F – FIXED POWER FACTOR

F1 General

The purpose of this test is to verify that the inverter complies with the requirement of Power factor specified in section 6.3 when it connects to the grid.

The inverter shall be placed in a test circuit equivalent to that shown in Figure 4 General

Test Setup.

F2 Test Procedure

The procedure shall be as follows:

- The inverter must be set so that it can operate between 0.80 leading to 0.80 lagging power factors at each level of active power supply.
- Regulate the DC/PV source so that the inverter can supply active power at 10 intervals of 10%; 20 %; 30%; …….; 100% with power factor set to unity.
- Record the values measured using a 200ms window at fundamental frequency using power analyzer for a time duration of 3 minutes. Calculate and report the average value from the recorded values for each active power levels. The power factor measured and reported shall be within ±0.01
- Repeat Steps b) and c) with the power factor set to 0.80 leading & 0.80 lagging.

F3 REACTIVE POWER LIMITS
The inverter should be able to operate with the required power factor as per section 6.3 and the values of absorbed (inductive) reactive power and supplied (capacitive) reactive power at each of the 10 measuring points as an absolute value shall be at least equal to 60% of the nominal active power of the inverter as specified in section 6.4.

F4 Test Report
The measured values shall be reported in a table format for each of the 10 intervals with the parameters for Active Power, Reactive power, Power factor and the input DC/PV power. Below table is an example.

Power Bin	Active Power [W]	Reactive Power [Var]	Power Factor (cosφ)	DC Power [W]
10%				
20%				
30%				
40%				
50%				
60%				
70%				
80%				
90%				
100%				

Table 4 Example Table for Power Factor

APPENDIX G – FIXED REACTIVE POWER

G1 General

The purpose of this test is to verify that the inverter complies with the requirement of Reactive power specified in section 6.4 when it connects to the grid.

The inverter shall be placed in a test circuit equivalent to that shown in Figure 4 General Test Setup.

G2 Test Procedure

The procedure shall be as follows:

- The inverter must be set so that it can respectively absorb (inductive) and supply (capacitive) the maximum reactive power available at each level of active power supply.
- Regulate the DC/PV source so that the inverter can supply active power at 10 intervals of [0-10] %; [10-20] %; [20-30] %; …….; [90-100] % with reactive power set to 0 (cosφ = 1).
- Record the values measured using a 200ms window at fundamental frequency using power analyzer for a time duration of 3 minutes. 3 values for the reactive power shall be calculated as 1-minute average values from the recorded values.
- Repeat Steps a) to c) with the reactive power set to maximum inductive and maximum capacitive.

G3 Reactive Power Limits

The values of absorbed (inductive) reactive power and supplied (capacitive) reactive power at each of the 10 measuring points as an absolute value shall be at least equal to 60% of the nominal active power of the inverter as specified in section 6.4.

G4 Test Report

The measured values shall be reported in a table format for each of the 10 intervals with the parameters for Active Power, Reactive power, Power factor and the input DC/PV power. Below table is an example.

Power Bin	Active Power [W]	Reactive Power [Var]	Power Factor (cosφ)	DC Power [W]
0% - 10%				
10% - 20%				
20% - 30%				
30% - 40%				
40% - 50%				
50% - 60%				
60% - 70%				
70% - 80%				
80% - 90%				
90% - 100%				

Table 5 Example Table for Fixed Reactive Power

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