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Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems

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Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems

1. Overview

This standard provides performance test specifications and requirements for inverters to be used in grid-tied photovoltaic systems.

1.1 Scope

This standard specifies the type test that shall be performed to measure and report the maximum continuous power rating, conversion efficiency, and tare losses of inverters used in grid-connected photovoltaic systems.

1.2 Purpose

Interconnection equipment that connects distributed resources (DR) to an electrical power system (EPS) are expected to do so efficiently. Standardized test procedures are necessary to establish methods for verifying inverter performance that leads to comparable results. These test procedures are provided as a repeatable, independent means of measuring inverter performance regarding maximum continuous power rating, conversion efficiency, and tare loss characteristics.

2. Normative references

a. IEEE Std 1547-2003 IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems. Sponsored by IEEE Standards Coordinating Committee 21 on Photovoltaics, Published by the IEEE, New York, NY, July 2003. Amended 2014 as IEEE Std 1547A.

b. IEEE 1547.1-2005 Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, Sponsored by IEEE Standards Coordinating Committee 21 on Photovoltaics, Published by the IEEE, New York, NY, June 2005.

3. Definitions

Area EPS: Electric Power System serving multiple customers (from IEEE Std 1547-2003).

Data Acquisition System (DAS): A system that receives data from one or more locations. (from IEEE Std. 100-1996)

Disconnect Switch: A switching device that breaks an electrical circuit. These devices may have ac or dc voltage and current ratings and may or may not be rated for breaking under load. Disconnect switches usually provide a visible break, and may have a locking feature to provide control over the status of the disconnect switch.

Efficiency: The ratio of the usable ac output power to the total dc + ac input power.

Electric Power System (EPS): (from IEEE Std 1547-2003), "Facilities that deliver electric power to a load".

Interconnection: The equipment and procedures necessary to connect an inverter or power generator to the utility grid. IEEE Std. 100-1996 Def: *The physical plant and equipment required to facilitate transfer of electric energy between two or more entities. It can consist of a substation and an associated transmission line and communications facilities or only a simple electric power feeder.*

Inverter: A machine, device, or system that changes direct-current power to alternating-current power. For the purposes of this test procedure, the inverter includes any input conversion (i.e., dc-dc chopper) that is included in the inverter package and any output device (i.e. transformer) that is required for normal operation.

Islanding: Continued operation of a photovoltaic generation facility with local loads after the removal or disconnection of the utility service. Unless provisions for disconnecting from the grid are included in the inverter system design, this is an unwanted condition that may occur in the rare instance of matched aggregate load and generation within the island.

I-V Curve: A plot of the photovoltaic array current versus voltage characteristic curve. The shape of IV curve is dependent on the PV cell technology, the configuration of the cells and other devices (e.g., bypass diodes) within the array, varying incident solar irradiance intensity and spectral content, and PV cell temperature.

Listed Equipment: Equipment, components or materials included in a list published by an organization acceptable to the authority having jurisdiction and concerned with product evaluation, that maintains periodic inspection of production of listed equipment or materials, and whose listing states either that the equipment or materials meets appropriate standards or has been tested and found suitable for use in a specified manner. (from the National Electrical Code; Article 100.)

Maximum Power Point: The point on the array I-V Curve that yields the greatest output power.

Maximum Power Point Tracker (MPPT): A function included in an inverter or in a separate device, that attempts to operate and maintain a PV array at its "Maximum Power Point."

Parallel / Paralleling: The act of synchronizing two independent power generators (i.e. the utility and a photovoltaic power plant) and connecting or "paralleling" them onto the same buss. In practice, it is used interchangeably with the term interconnection. IEEE 100 Def.: "The process by which a generator is adjusted and connected to run in parallel with another generator or system."

Power Conditioning Subsystem (PCS): The subsystem (Inverter) that converts the dc power from the array subsystem to ac power that is compatible with system requirements. (From 100-1996) See also Inverter.

Power Conditioning Unit, PCU: A device that converts the dc output of a photovoltaic array into utility-compatible ac power. The PCU (Inverter) may include (if so equipped) the array maximum power tracker, protection equipment, transformer, and switchgear. See also Inverter, Power Conditioning Subsystem (PCS), and Static Power Converter (SPC).

Power foldback: An operational function whereby the unit reduces its output power in response to high temperature, excessive input power, or other conditions.

Simulated Utility: an assembly of voltage and frequency test equipment replicating a utility power source. Where appropriate, the actual Area EPS can be used as the Simulated Utility. (From IEEE P1547.1)

Static Power Converter: A device with control, protection, and filtering functions used to interface an electric energy source with an electric power system. Sometimes referred to as inverter, power conditioning subsystem, power conversion system, solid-state converter, or power conditioning unit. (Preceding is derived from 100-1996). The term solid-state inverter is intended to differentiate a solid-state device from a mechanical motor-generator type converter. See Inverter.

Supervisory Control and Data Acquisition (SCADA): Utility equipment used to monitor and control power generation, transmission, and distribution equipment. (IEEE Std 100 Def): *A system operating with coded signals over communication channels so as to provide control of remote equipment (using typically one communication channel per remote station).* The supervisory system may be combined with a data acquisition system, by adding the use of coded signals over communication channels to acquire information about the status of the remote equipment for display or for recording functions.

Utilization: (Array Utilization): The ratio of the energy (or power) that is actually extracted from the module or array to the maximum energy (power) potentially available from the array. Array utilization less than 1.0 is a result of inaccurate Maximum Power Point Tracking

Utility: For this document, the organization having jurisdiction over the interconnection of the photovoltaic system and with whom the owner may enter into an interconnection agreement. This may be a traditional electric utility, a distribution company, or some other organization. IEEE 100 Def: *An organization responsible for the installation, operation, or maintenance of electric supply or communications systems.*

4. List of Acronyms

ASTM	American Standards for Testing Materials
DAS	Data Acquisition System
dpf	Displacement Power Factor
EMC	Electromagnetic Compatibility
EPS	Electric Power System
FF	Fill Factor
FCC	Federal Communications Commission
Hz	Hertz (Cycles per second)
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEEE	Institute for Electrical and Electronics Engineers
Imp	PV Array Maximum Power Current
Isc	PV Array Short Circuit Current

MPPT	Maximum Power Point Tracking
NEC	National Electrical Code
OFP	Over Frequency Protection Device or Method
OVP	Over Voltage Protection Device or Method
PCC	Point of Common Coupling
PCS	Power Conversion System
Pf	Power Factor
Pmp	PV Array Maximum Power (Imp * Vmp)
PTC	PVUSA Test Conditions
RMS	Root-mean-square
RFI	Radio Frequency Interference
SCADA	Supervisory Control and Data Acquisition
SPC	Static Power Converter
SRC	Standard Reporting Conditions
STC	Standard Test Conditions
THD	Total Harmonic Distortion
UFP	Under Frequency Protection Device or Method
UL	Underwriters Laboratories, Inc.
UUT	Unit Under Test
UVP	Under Voltage Protection Device or Method
Vmp	PV Array Maximum Power Voltage
Voc	PV Array Open Circuit Voltage
Z	Impedance

5. General Requirements

To provide a power flow convention, power from the inverter to the simulated utility is considered positive and power from the simulated utility to the inverter is considered negative.

For tests requiring stabilized operating temperature, temperatures are considered to be stable when three successive readings taken at not less than 30 minute intervals following an initial 150 minutes of operation indicates no more than 1°C (1.8 °F) variation between any two readings. Shorter durations may be used if it can be demonstrated that the unit has reached thermal stability

5.1 Measurement accuracy and calibration of the testing equipment

Unless otherwise specified, the requirements in this section apply to all test procedures Basic measurement requirements are provided inTable 1.

Table 1. Basic Measurement Requirements

Parameter		Allowed Maximum Uncertainty
DC Voltage*		± 0.25% of reading
AC Voltage**		± 0.25% of reading
DC Current*		± 0.5% of reading
AC Current**		± 0.5% of reading
DC Power*		± 0.5% of reading
AC Power**		± 0.5% of reading
AC Frequency		± 0.01 Hz
Temperature		±0.5°C
DC Current Ripple		± 1% of reading

*Note: The ac ripple on the dc line must be taken into account when the magnitude of the current or voltage ripple is >2% of the dc magnitude. Power measurements made through electronic sampling and mathematical integration must take the voltage ripple and current ripple phase difference into account when either magnitude is >2% of the dc magnitude.

**Note: The ac power measurement should include only the usable 60Hz power.

Though some of the wording of this document implies a data acquisition system, any suitable equipment that provides the necessary functionality and accuracy may be used to perform these tests.

Input voltages and currents are measured at the input terminals of the UUT or between the input supply (e.g., PV array) and the connection point of any optional or ancillary equipment external to the UUT. Output voltages and currents are measured at the output terminals of the UUT or at output terminals of the supplied/required external transformer.

Ambient air temperature shall be measured at least 6 inches (15 cm) horizontally away from the enclosure and at the mid-point of the height of the enclosure, and out of the UUT's convection or forced airflow. Ambient air movement will be minimized to only that necessary to maintain ambient temperature at the specified level. When an environmental chamber is used to control temperature, shrouds or secondary enclosures may be needed to meet this requirement.

Inverter temperature shall be measured at the switching device, or as close as practical.

5.2 Inverter DC Input Power Supply Requirements

For efficiency measurements the inverter dc input supply shall meet the following minimum specifications. For this test, the dc input supply does not necessarily have to provide a PV-like I-V curve, such as defined in Appendix A.3, though such a power supply or an appropriately sized PV array may be used. It should meet as a minimum the following requirements:

a. a maximum voltage ripple of 1.0% over the range of expected operation

b. sufficient rated output so that limitations of the power supply do not affect the results (e.g., rated continuous output exceeding 100% of the inverter rated input over the range of inverter input voltage

c. Adjustable output voltage range of at least the inverter's rated input voltage range

d. Voltage regulation within +/- 2% for all DC voltage settings and across the entire load range from 10% to 100% of rated power output.

When the dc source has little or no surge limitations, external series R/L impedance inserted between the power supply output and inverter input may be necessary to

- limit surges to the inverter
- isolate the power supply output from the inverter input and eliminate unwanted interactions (i.e. the dc supply regulator controlling the operating point of the inverter or visa-versa)
- isolate the power supply output capacitors to limit the change in absolute value of magnitude of the voltage ripple to no less than 90% of measured values using a properly sized PV array.

Resistance, inductance and capacitance shall remain within ±5% of recorded values during the entire test. Ratings of the components shall be at least 150% of the dissipated power, current, and voltage.

The PV array simulator described in Annex A.3 may be used in lieu of a real PV array to provide a current-voltage characteristic curve (I-V curve) representative of a variety of PV technologies, when such characteristics affect the test results.

When an actual PV array is used as the input source, the supply cabling should be large enough to limit voltage drop to less than 2% of the nominal Vdc.

5.3 Inverter AC Output (Simulated Utility) Power Supply Requirements

For efficiency measurements the ac output power supply (simulated utility) shall meet the following minimum specifications (a combination of an AC power supply and load bank may be used to satisfy this requirement):

a. Maximum THD of 2.5% and not influenced by the output current of the inverter

b. Maximum impedance at 60Hz less than 5 percent of the inverter output impedance where the inverter output impedance is equal to the inverter rated output voltage divided by the inverter rated output current at unity displacement power factor (Inverter Rated Output Power)/(Inverter Output Current at Rated Power) at fundamental frequency. (The impedance may be a series/parallel combination of resistance and inductance so as to present reasonable impedance at all frequencies while limiting losses)

c. Rated power input (sink) of at least 150% of the inverter rated output at 60Hz

d. Ability to sink full power over the entire operating voltage range of the inverter

e. Adjustable voltage and frequency ranges at least equal to those of the inverter under test and continuously or in increments of at least ±5% of maximum

f. Frequency stability – frequency shall not change by more than ±0.1 Hz during any single test

g. Respond to a step change of ±50% of maximum power without causing more than a 5% change in output voltage

h. Time-constants associated with the reference waveform that are consistent with changes expected in output power associated with these tests

i. Slew rate for voltage of at least 10 Volts/cycle

j. Slew rate for frequency of at least 1 Hz/cycle

k. Ability to withstand instantaneous switching to open circuits at the output

6. Type Tests

Type tests are performed on a representative unit and may be conducted in the factory, at a test laboratory, or on equipment in the field.

6.1 Maximum Continuous Real and Apparent Power Output

This test will establish the maximum output real and apparent power levels that the unit can maintain for a period of not less than 180 minutes at an ambient operating temperature of 40°C after reaching thermal equilibrium. Both the inverter's maximum output apparent power rating and corresponding output real power rating must be recorded prior to testing. The inverter's maximum output apparent power rating and the output real power rating will correspond to the inverter's displacement power factor rating. For inverters with a displacement power factor rating of less than unity, the apparent power tests will be performed first with a leading displacement power factor and then with a lagging displacement power factor.

The displacement power factor rating established for this test will be used as part of the Conversion Efficiency Test. For an inverter that is tested for Maximum Continuous Power Output at only unity displacement power factor, the follow-on Conversion Efficiency Test will be performed at only unity displacement power factor.

6.1.1 Comments

The chosen displacement power factor ratings should be representative of the inverter's capabilities, and should reflect the inverter's specification. Additionally, the displacement power factor rating should readily facilitate comparisons and calculations regarding displacement power factor capabilities and performance.

For clarity regarding displacement power factor ratings, this protocol assumes the convention that an inverter is a source of generation where real current flow to the grid is described as positive current:

- For non-unity operation, where the current lags the voltage, the inverter is producing a lagging displacement power factor.
- For non-unity operation, where the current leads the voltage, the inverter is producing a leading displacement power factor.

In all cases of the following tests, the ac output will be measured on the utility side of any manufacturer-required transformer. If not supplied by the manufacturer, a transformer meeting or exceeding the manufacturer's minimum specifications will be obtained. Test records shall describe any transformers included in the measurements and state whether such transformers are supplied or required by the manufacturer.

Optional or ancillary equipment, including fans, displays, etc., shall be included in the measurement (that is, the power that the equipment draws will either be added to the input power level or subtracted from the output power level).

Such equipment shall be operated at its maximum power level and duty cycle during each measurement. Testing may be repeated without optional equipment. These results must be clearly distinguished as "without optional equipment".

In the case where multiple inverters are designed to share a common transformer, individual inverters will be measured on the inverter side of the transformer.

Transformer losses (in Watts or kW) will be measured independently at the various power levels and when multiple inverters are to be connected to a single transformer, the measured loss shall be divided by the minimum number of inverters that are normally connected. The resulting loss fraction will then be used in the efficiency calculation for a single inverter (i.e., the inverter output will be reduced by that

amount).

Inverters that provide more than one nominal ac voltage (e.g., 208Vac and 240Vac) shall be tested as though each nominal voltage signified a different model of inverter.

Inverters with multiple inputs shall be tested with all inputs activated. Testing may be repeated with fewer inputs active. These results must be presented with the number of inputs active.

Additional testing may be performed at lower temperatures, specified by the manufacturer. These results must be clearly distinguished as "reduced temperature" values.

The input power source must be capable of providing 150% of the maximum input power rating of the UUT over the entire range of UUT input voltages.

This test may be performed simultaneously with the corresponding conditions in Section6.2 Conversion Efficiency.

6.1.2 Procedure

Prior to performing the test, the unit shall be stored at 45±5°C (113±9°F) for a minimum of 24 hours. At the beginning of the test, the unit shall be operated at the 100% apparent power level, with an ambient temperature of 40°C for at least 2.5 hours and until the inverter temperature measurement (on the switching device heat sink) stabilizes.

1. Test done at nominal frequency (50 Hz or 60 Hz) ±0.1Hz.
2. Input voltages and currents are measured at the input terminals of the inverter or between the input supply and the connection point of any optional or ancillary equipment if such equipment is not sourced internal to the UUT. Output voltages and currents are measured

at the output terminals of the inverter or at output terminals of the manufacturer supplied/required external transformer. Record the transformer specifications.

3. Vnom = For ac, this is the manufacturer specified nominal ac operating voltage. For dc, Vnom may be selected by the manufacturer at any point between Vmin+0.25*(Vmax-Vmin) and Vmin+0.75*(Vmax-Vmin).
4. Maintain the UUT in an environment of at least 45°C for a minimum of 24 hours before testing to help ensure that unit is relatively warm at the beginning of the test and that step 2) will bring the unit to a stable operating temperature in a reasonable period of time.
5. Adjust the test environment air temperature to 40°C ±3°C.
6. Connect the UUT according to the instructions and specifications provided by the manufacturer to the selected input and output power sources.
7. Set all input source parameters to the nominal operating conditions for the UUT.
8. Set (or verify) all UUT parameters to the nominal operating settings.
9. Set the UUT (including the input source as necessary) to provide 100% of its rated output apparent power and corresponding rated output real power. If these settings result in a non-unity displacement power factor, set the UUT to produce a leading or lagging displacement power factor, as required in Table 1-2. The UUT must achieve the required displacement power factor at the output. The commanded displacement power factor may differ from the resultant output displacement power factor as necessary to achieve the required displacement power factor at the inverter's output.
10. Record all applicable settings.
11. Set the input source to provide the power level necessary to achieve the desired output power level and at the nominal input voltage.
12. Set the simulated utility to provide the nominal ac voltage.
13. Allow the unit to operate for at least 150 minutes and until the heat sink temperature stabilizes.
14. After allowing the inverter heat sink temperature to stabilize, measure and record the following values at 5 minute intervals for at least 180 minutes (continuous sampling at higher data rates and 5 minute averages is preferred):
    a. Input voltage (dc and ac)
    b. Input current (dc and ac)
    c. Input power (average dc + ac RMS)
    d. Output voltage (ac)
    e. Output power (ac)
    f. Ambient temperature (°C)
    g. Inverter temperature at heat sink (°C).
15. If the unit shuts down, reduce the input power by an amount specified by the manufacturer and begin again. If the test is restarted with no delay, some allowance may be given in the temperature stabilization in Step 13 for heating that has already occurred.

16. Repeat steps 7)-15) for Test Conditions B and C in Table 2. If tests are run consecutively then the 150 minute temperature soak in step 10 may be skipped. Additionally, the sampling time period may be reduced to 60 minutes for Test Conditions B and C.

Table 2. Maximum Continuous Output Power Test Conditions

Test	Vdc	Vac	Power Factor	Maximum Apparent Power (kVA)	Real Power (kW)	Reactive Power (kVAR)	Power Factor
A	Vnom	Vnom	Leading				
B	Vnom	Vnom	Lagging				
C	Vnom	Vnom	Unity				

6.1.3 Reported Values

In addition to tabular and graphical presentation of the measured data, the unit performance report shall include the following values:

For each Test Condition, calculate and report inTable 2:

a. AC Output Apparent Power, AC Output Real Power, AC Output Reactive Power, and AC Output Displacement power factor (minimum of the 5-minute averages or sampled values)

b. The unit Maximum Continuous Apparent Output for Leading and Lagging Displacement power factor will be stated as the minimum corresponding values (Leading and Lagging) recorded inTable 2. The unit Maximum Continuous Real Output Power will be stated as recorded inTable 2.

c. For temperatures below 40°C, values shall be reported as Reduced Temperature Continuous Output Apparent Power (XX °C), Reduced Temperature Continuous Output Real Power (XX °C), Reduced Temperature Continuous Output Reactive Power and Reduced Temperature Output Displacement power factor.

6.2 Conversion Efficiency

This test is intended to establish the conversion efficiency of the inverter between the dc source (PV) input and the ac output. The series of tests described in this section will characterize the unit's efficiency as a function of output apparent power, real power, array voltage, utility voltage, and ambient temperature.

6.2.1 Comments

The conversion efficiency shall be measured at the inverter's minimum leading displacement power factor, the minimum lagging displacement power factor and unity displacement power factor. For inverters that are rated only for unity displacement power factor, the non-unity tests shall be omitted. The non-unity displacement power factor tests shall be performed at the Apparent Power rating stated for the Maximum Continuous Apparent Power Output test.

In all cases of the following tests, the ac output will be measured on the utility side of any manufacturer-required transformer. If not supplied by the manufacturer, a transformer meeting or exceeding the manufacturer's minimum specifications will be obtained and used. Test records shall describe any transformers included in the measurements and state whether such transformers are supplied or required by the manufacturer.

Optional or ancillary equipment, including fans, displays, etc., shall be included in the measurement (that is, the power that the equipment draws will either be added to the input power level or subtracted from the output power level).

Such equipment shall be operated at its maximum power level and duty cycle during each measurement. Testing may be repeated without optional equipment. These results must be clearly distinguished as "without optional equipment".

In the case where multiple inverters are designed to share a common transformer, individual inverters will be measured on the inverter side of the transformer.

Transformer losses (in W or kW) will be measured independently at the various power levels and when multiple inverters are to be connected to a single transformer, the measured loss shall be divided by the minimum number of inverters that are normally connected. The resulting loss fraction will then be used in the efficiency calculation for a single inverter (i.e., the inverter output will be reduced by that amount).

For the following test, the inverter shall be installed in the test fixture according to the manufacturer's instruction in a manner that is representative of typical field installations. To ensure that the unit achieves realistic internal temperatures, all covers and enclosures shall be installed (for example, a secondary enclosure, if required for outdoor installation). Ambient air movement will be minimized to only that necessary to maintain ambient temperature at the specified level. When an environmental chamber is used to control temperature, shrouds or secondary enclosures may be needed to meet this requirement.

6.2.2 Procedure

Prior to performing the test, the unit shall be stored at 45°C for a minimum of 24 hours. At the beginning of the test, the unit shall be operated at the 100% power level for at least 2.5 hours and until the inverter temperature measurement (on the switching device heat sink) stabilizes.

Care should be taken to annotate results that occur with the unit in a power foldback mode. When power foldback occurs, mark "Foldback" in the recording sheet and note that power foldback has occurred along with the details of the situation.

Table 3 lists the matrix of test conditions under which inverters will be evaluated in this test. The empty cells are for recording measured or calculated results.

If possible, the operation of the MPPT should be disabled to reduce the measurement error that would be associated with changes in operating point. If this is not possible, it is important that the monitoring equipment sampling rate must be at least 5 times the MPPT dithering rate and must ensure nearly simultaneous measurement of input and output electrical parameters. Suitable averaging is then used to eliminate the influence of MPPT. It is also important that the simulator response to inverter MPPT operation accurately represent inverter performance when tied to a real PV array.

Inverters that provide more than one nominal ac voltage (e.g., 208 Vac and 240 Vac) shall be tested as though each nominal voltage signified a different model of inverter.

Inverters with multiple inputs shall be tested with all inputs activated. Testing may be repeated with fewer inputs active. These results must be presented with the number of inputs active.

A battery shall be included in the measurement setup if it is included in the normal operation of the inverter and if the dc input source is unable to maintain the desired voltage without excessive ripple. For the performance of this test, the battery shall be maintained at full charge during all measurements (this requirement will necessitate the installation of a separate battery charger to address battery losses during the measurements).

If a PV Array simulator, as described in Annex A3, is used for this test, the simulated PV array is assumed to be at reference conditions, nominal fill factor = 0.68, and with the voltage and power scaled to provide the prescribed conditions (described in Annexes A1 and A2).

a. Tests done with the MPPT disabled, if possible. Indicate status on data report.

b. Test done at nominal frequency (50 Hz or 60 Hz) ±0.1Hz.

c. Input voltages and currents are measured at the input terminals of the inverter or between the input supply and the connection point of any optional or ancillary equipment if such equipment is not sourced internal to the UUT. Output voltages and currents are measured at the output terminals of the inverter or at output terminals of the manufacturer supplied/ required external transformer. Record the transformer specifications.

d. Vnom: For ac, this is the manufacturer specified nominal ac operating voltage. For dc, Vnom may be selected by the manufacturer at any point between Vmin+0.25*(Vmax-Vmin) and Vmin+0.75*(Vmax-Vmin).

e. Vmin: Manufacturer-specified minimum operating ac or dc voltage. The minimum dc operating voltage may be a function of the ac operating voltage. If so, use the manufacturer’s specifications to determine the proper minimum dc voltage for each test.

f. Vmax: Manufacturer-specified maximum ac or dc operating voltage. The maximum dc operating voltage may be a function of the ac operating voltage. If so, use the manufacturer’s specifications to determine the proper maximum dc operating voltage for each test. For inverters used with PV, the maximum dc operating voltage should not exceed 80% of the units maximum rated system voltage (maximum allowable array open circuit voltage).

g. Allowable tolerance on input power level is as follows:

Table 3. Power Tolerance

Power	Tolerance	Power	Tolerance
10%	8%-12%	50%	45%-55%
20%	18%-22%	75%	70%-80%
30%	27.5%-32.5%	100%	95%-105%

*Note: When conducting this test, use caution that the inverter does not power limit when the 100% level is exceeded.

h. Maintain the UUT in an environment of at least 45°C for a minimum of 24 hours before testing to help ensure that unit is warmer than 25°C at the beginning of the test and that step 2) will bring the unit to a stable operating temperature in a reasonable period of time. If the Conversion Efficiency Test is performed within one hour of the full load operation performed under test 6.1 and the unit has not been exposed to ambient temperature less than 22 °C, then the warming at 45°C for 24 hours is not required.

i. Adjust the test environment air temperature to 25 °C ±3 °C.

j. Adjust the input and output source operating voltages (Vdc, and Vac) to nominal values and adjust the input source power to provide 100% of rated output, at the unit's Maximum Continuous Apparent Output Power for the Minimum Leading Displacement power factor setting.

k. Allow the unit to operate for at least 150 minutes to bring electronic circuits and components to a stable operating temperature. If the Conversion Efficiency Test is performed within one hour of the full load operation under test 6.1, then the full load operation interval can be reduced from 150 minutes to 60 minutes.

l. Adjust the input source operating voltage (Vdc) to the Test "A" level shown in Table 2.

m. Adjust the output source operating voltage (Vac) to nominal. Adjust the output source frequency to nominal.

n. Adjust the input source power or the inverter's current/power command to the Test "A" (100%) level shown in Table 2. Note – the 100% Output Power Level shall for unity power factor be performed at 100% Real Power, and for the stated displacement power factor shall be performed at 100% Apparent Power.

o. After allowing the inverter heat sink temperature to stabilize, measure and record the following values at 30 second intervals for at least 3 minutes (continuous sampling at higher data rates is preferred):

    1) Input voltage (dc and ac)
    2) Input current (dc and ac)
    3) Input power (average dc + ac RMS)
    4) Output voltage (ac)
    5) Output power, apparent and real (ac)
    6) Displacement power factor
    7) Ambient temperature (°C)
    8) Inverter temperature at heat sink.

p. Repeat steps l) through o) for the remaining 100% Output Power Levels for all Vdc settings and for all displacement power factor settings, as shown in the Figure 1 example. . If tests are run consecutively, the 150 minute temperature soak in step 10 may be skipped.

q. Repeat steps l) through o) for all remaining power levels and all remaining displacement power factors shown in Figure 1. The tests may optionally be performed such that the inverter's losses are decreasing monotonically. To achieve monotonically decreasing losses for some inverters, the order of the tests will differ from the order described.

However, the intent remains the same – the inverter's losses and therefore the inverter's heat sink temperature should be decreasing monotonically as the tests progress.

r. The requirement is to obtain 5 sets of results for each condition. Outliers (data points more than 3 standard deviations beyond the average) should be documented and those measurement points repeated.

6.2.3 Reported Values

In addition to tabular and graphical presentation of the measured data, the unit performance report shall include the following values.

For each Power Level at each Test Condition, calculate and report:

a. Average DC Input Power (average of five sampled values)

b. Average AC Output Power (average of five sampled values)

c. Efficiency = Average AC Output Power/Average DC Input Power. These are the values to be entered into Figure 1.

Minimum Leading Power Factor: 0.9

Rated Output Apparent Power: 1.0 kVA **Rated Output Real Power:** 0.9 kW

Vmin: 300 Vdc Vnom: 360 Vdc Vmax: 480 Vdc

			Inverter AC Output Real Power Level at Stated Power Factor					
Test	Vdc	Vac	10%	20%	30%	50%	75%	100%
C	Vmin	Vnom						
B	Vnom	Vnom						
A	Vmax	Vnom						

Resultant Efficiency = ________

Minimum Lagging Power Factor: 0.9

Rated Output Apparent Power: 1.0 kVA **Rated Output Real Power:** 0.9 kW

Vmin: 300 Vdc Vnom: 360 Vdc Vmax: 480 Vdc

			Inverter AC Output Real Power Level at Stated Power Factor					
Test	Vdc	Vac	10%	20%	30%	50%	75%	100%
C	Vmin	Vnom						
B	Vnom	Vnom						
A	Vmax	Vnom						

Resultant Efficiency = ________

Power Factor: Unity

Rated Output Apparent Power: 1.0 kVA **Rated Output Real Power:** 1.0 kW

Vmin: 300 Vdc Vnom: 360 Vdc Vmax: 480 Vdc

			Inverter AC Output Real Power Level at Unity Power Factor					
Test	Vdc	Vac	10%	20%	30%	50%	75%	100%
C	Vmin	Vnom						
B	Vnom	Vnom						
A	Vmax	Vnom						

Resultant Efficiency = ________

Figure 1. Efficiency Test Results Summary (with example test settings)

Unit Under Test Rating	**Power Factor**	**Rated VA**	**Rated kW**
Minimum Leading Power Factor:	______	______	______
Minimum Lagging Power Factor:	______	______	______
Unity Power Factor:	1.0	______	______

Vmin: ______ **Vdc** **Vnom:** ______ **Vdc** **Vmax:** ______ **Vdc**

Specified			Sample #1 (Minimum of 5 Samples at Each Power Level Required)									
Power Factor Required	Output Power	Input Voltage	Power Factor Command	Input Voltage	Input Current	Pdc	Vac	Iac	Pac	AC VA	Power Factor	Efficiency
	(% of rated)	(Vdc)		(Vdc)	(Idc)	(watts)	(Volts)	(Amps)	(AC watts)	(VA)	(Vdc)	(%)
0.9 Leading	100%	Vmax										
0.9 Leading	100%	Vnom										
0.9 Leading	100%	Vmin										
0.9 Lagging	100%	Vmax										
0.9 Lagging	100%	Vnom										
0.9 Lagging	100%	Vmin										
Unity	100%	Vmax										
Unity	100%	Vnom										

Specified			Sample #1 (Minimum of 5 Samples at Each Power Level Required)									
Power Factor Required	Output Power	Input Voltage	Power Factor Command	Input Voltage	Input Current	Pdc	Vac	Iac	Pac	AC VA	Power Factor	Efficiency
	(% of rated)	(Vdc)		(Vdc)	(Idc)	(watts)	(Volts)	(Amps)	(AC watts)	(VA)	(Vdc)	(%)
0.9 Leading	75%	Vmax										
0.9 Leading	75%	Vnom										
0.9 Leading	75%	Vmin										
0.9 Lagging	75%	Vmax										
0.9 Lagging	75%	Vnom										
0.9 Lagging	75%	Vmin										
Unity	75%	Vmax										
Unity	75%	Vnom										
Unity	75%	Vmin										

Specified			Sample #1 (Minimum of 5 Samples at Each Power Level Required)									
Power Factor Required	Output Power	Input Voltage	Power Factor Command	Input Voltage	Input Current	Pdc	Vac	Iac	Pac	AC VA	Power Factor	Efficiency
	(% of rated)	(Vdc)		(Vdc)	(Idc)	(watts)	(Volts)	(Amps)	(AC watts)	(VA)	(Vdc)	(%)
0.9 Leading	50%	Vmax										
0.9 Leading	50%	Vnom										
0.9 Leading	50%	Vmin										
0.9 Lagging	50%	Vmax										
0.9 Lagging	50%	Vnom										
0.9 Lagging	50%	Vmin										
Unity	50%	Vmax										
Unity	50%	Vnom										
Unity	50%	Vmin										

Specified			Sample #1 (Minimum of 5 Samples at Each Power Level Required)									
Power Factor Required	Output Power	Input Voltage	Power Factor Command	Input Voltage	Input Current	Pdc	Vac	Iac	Pac	AC VA	Power Factor	Efficiency
	(% of rated)	(Vdc)		(Vdc)	(Idc)	(watts)	(Volts)	(Amps)	(AC watts)	(VA)	(Vdc)	(%)
0.9 Leading	30%	Vmax										
0.9 Leading	30%	Vnom										
0.9 Leading	30%	Vmin										
0.9 Lagging	30%	Vmax										
0.9 Lagging	30%	Vnom										
0.9 Lagging	30%	Vmin										
Unity	30%	Vmax										
Unity	30%	Vnom										
Unity	30%	Vmin										

Specified			Sample #1 (Minimum of 5 Samples at Each Power Level Required)									
Power Factor Required	Output Power	Input Voltage	Power Factor Command	Input Voltage	Input Current	Pdc	Vac	Iac	Pac	AC VA	Power Factor	Efficiency
	(% of rated)	(Vdc)		(Vdc)	(Idc)	(watts)	(Volts)	(Amps)	(AC watts)	(VA)	(Vdc)	(%)
0.9 Leading	20%	Vmax										
0.9 Leading	20%	Vnom										
0.9 Leading	20%	Vmin										
0.9 Lagging	20%	Vmax										
0.9 Lagging	20%	Vnom										
0.9 Lagging	20%	Vmin										
Unity	20%	Vmax										
Unity	20%	Vnom										
Unity	20%	Vmin										

Specified			Sample #1 (Minimum of 5 Samples at Each Power Level Required)									
Power Factor Required	Output Power	Input Voltage	Power Factor Command	Input Voltage	Input Current	Pdc	Vac	Iac	Pac	AC VA	Power Factor	Efficiency
	(% of rated)	(Vdc)		(Vdc)	(Idc)	(watts)	(Volts)	(Amps)	(AC watts)	(VA)	(Vdc)	(%)
0.9 Leading	10%	Vmax										
0.9 Leading	10%	Vnom										
0.9 Leading	10%	Vmin										
0.9 Lagging	10%	Vmax										
0.9 Lagging	10%	Vnom										
0.9 Lagging	10%	Vmin										
Unity	10%	Vmax										
Unity	10%	Vnom										
Unity	10%	Vmin										

Figure 2. Efficiency Raw Data Report Format (with sample setting)

The unit Weighted Efficiency is a useful comparative tool for designers and consumers, as systems are installed in a wide range of solar resource regimes. The value of the Weighted Efficiency can be roughly estimated by assigning a percentage of time the inverter resides in a particular range of operation, summing the products of (% time) X (efficiency)/100 to approximate the integral of efficiency X time over the full day. For instance, if the inverter is oversized for the system and the solar resource is marginal, the Weighted Efficiency would be a better predictor of system performance. Weighted Efficiency is calculated using the data taken at the various levels of power according to the equation

$$\eta_{Wtd} = F_1\eta_{10} + F_2\eta_{20} + F_3\eta_{30} + F_4\eta_{50} + F_5\eta_{75} + F_6\eta_{100}$$

where

η_{10}, η_{20}, η_{30}, etc. are measured efficiency values at 10%, 20%, 30%, etc. of rated power, recorded in Test A, Table 2, and

F_1, F_2, F_3, etc. are the weighting factors defined in Table 4 below:

Table 4. Weighting factors for calculating Weighted Efficiency

Factor	Inverter Power Level	High-Insolation [1]	Low-Insolation [2]
F1	10%	0.04	0.09
F2	20%	0.05	0.13
F3	30%	0.12	0.10
F4	50%	0.21	0.48
F5	75%	0.53	0.00
F6	100%	0.05	0.20

[1] – Based on irradiance and temperature data representative of Southwest US.
[2] – Also known as European Efficiency.

6.3 Tare Losses

This test determines the utility ac power required to operate the unit in standby mode (nighttime Tare losses).

6.3.1 Test Procedure

To perform this test, it may be necessary to defeat or disable functions (e.g., timers) that might interfere with the results. The tests shall be performed at ambient temperature (25 ± 3 °C)

1. Begin inverter in standby mode, input dc voltage and power at zero, and simulated utility voltage and frequency at nominal levels.
2. Record the power level to or from the simulated utility.

6.3.2 Reported Value

Power flow from the grid to the inverter under test shall be reported as positive losses. Results of this test shall be reported as:

Night Tare Loss = P_{ac} when $V_{dc} = 0$

7. Annexes

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