

Guideline for the use of the Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems

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1 Overview

The purpose of this guideline is to provide additional information to testing laboratories and inverter manufacturers as to the intent of the inverter test protocol, posted on the web November 22, 2004 (http://www.energy.ca.gov/renewables/02-REN-1038/documents/2004-12-01_INVERTER_TEST.PDF) and the stipulations relating to that protocol called out in the California Energy Commission (CEC) Emerging Renewables Program (ERP) Guidebook, 4th Edition, posted on the web in January 2005 (<http://www.energy.ca.gov/2005publications/CEC-300-2005-001/CEC-300-2005-001-ED4F.PDF>). A meeting was held with the Nationally Recognized Testing Laboratories (NRTLs) at the CEC offices in Sacramento on February 25, 2005 to discuss the application of the test protocol as it relates to the CEC. This guideline is a result of that meeting and is intended to document and summarize the discussions for those in attendance and others who will be applying the guideline who were. The reader is also referred to the presentations from that meeting for additional guidance.

2 Adopted Test Procedures and Criteria

2.1 *Appendix 3 - Criteria for Listing Components as Eligible*

The 4th Edition of the ERP Guidebook has an Appendix 3 that deals with the eligibility requirements for components to be listed for use in the ERP. Section 3.E. specifically deals with the eligibility requirements for inverters. This section employs shading to differentiate the different the two documents used in this guideline. The yellow shading signifies sections from the CEC ERP Guidebook, 4th Edition. The blue shading signifies the sections from the Sandia *Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems*. The unshaded portions of the text in this section are explanatory in nature to provide a better understanding of the intent and application of the testing protocol.

E. Inverters

All inverters must be certified as meeting the requirements of UL 1741. In addition, for each model of inverter further testing is required to be done by a qualified Nationally Recognized Test Laboratory¹⁵ to remain eligible for this program. Beginning April 1, 2005, only inverters that have completed the testing will be listed as eligible equipment.

Inverter ratings for each model will be determined according to sections of the test protocol entitled, *Performance Test Protocol for Evaluating Inverters Used in Grid-Connected Photovoltaic Systems*, prepared by Sandia National Laboratories, Endecon Engineering, BEW Engineering, and Institute for Sustainable Technology, October 14, 2004 version.¹⁶ This version of the report is available on the Energy Commission web site at [www.consumerenergycenter.org/erprebate/equipment.html]. The tests must be performed in accordance with sections 3, 4, 5.1 and 5.2. The following tests are required:

The first paragraph in section E states that inverters must be certified to both UL1741 and the Sandia Performance Protocol. This testing shall be performed by a NRTL approved by OSHA to conduct test UL 1741. Currently three labs have this approval, (1) Underwriters Laboratories (UL), (2) Intertek ETL Semko (ETL), and, (3) Canadian Standards Association (CSA). One lab, TÜV Rheinland of North America (TÜV) is in process with their OSHA approval and should have that approval in place shortly.

Inverters must be tested in accordance with sections 3, 4, 5.1, and 5.2 of the Sandia Test Protocol. Sections 3 and 4 cover safety and an overview of the testing considerations. The test procedures are found in Section 5 with section 5.1 covering the general requirements and section 5.2 covering the test equipment requirements.

¹⁵ Nationally Recognized Testing Laboratories shall be those laboratories that have been recognized by the U.S. Department of Labor, Occupational Safety & Health Administration (OSHA), in accordance with Title 29 of the Code of Federal Regulations, section 1910.7, and are approved to conduct test UL 1741 under the scope of their OSHA recognition. A list of all current Nationally Recognized Testing Laboratories is available on OSHA's web page at [www.osha.gov/dts/otpca/nrtl/index.html]. Please note, not all of the Nationally Recognized Testing Laboratories identified on OSHA's list are approved to conduct test UL 1741.

¹⁶ This version of the test protocol is identified by the file name "InvertrTestProto_041014.doc" as shown in the left-hand side of the footer on each page of the protocol.

5.1 General Requirements

For 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.

Section 5.1 states that the inverter must reach temperature stabilization before the testing can begin. Some inverters may have an oscillating operating temperature based upon the cycling of cooling fans. In this case, temperature stabilization would be the point at which the highest operating temperature is reached. Very large inverters may have magnetics that take more than 10 hours to reach stabilized temperature. This protocol only requires stabilization of the heat sink temperature as a practical consideration.

5.2 Test Equipment Requirements

Unless otherwise specified, the requirements in this section apply to all test procedures Basic measurement requirements are provided in Table 2-1.

Table 2-1 Basic Measurement Requirements

Parameter True RMS (V,I,P)	Allowable Maximum Uncertainty	Preferred Maximum Uncertainty
DC Voltage*	± 1% of reading	± 0.25% of reading
AC Voltage	± 1% of reading	± 0.25% of reading
DC Current*	± 1% of reading	± 0.5% of reading
AC Current	± 1% of reading	± 0.5% of reading
DC Power*	± 1% of reading	± 0.5% of reading
AC Power**	± 1% of reading	± 0.5% of reading
AC Frequency	± 0.05 Hz	± 0.01 Hz
Temperature	±1°C	±0.5°C
DC Current Ripple	± 5% of reading	± 1% of reading

*Note: "True RMS" measurements must be made for voltage and current. "True RMS" instruments include the contribution of the ac ripple on dc values in the measurement. 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.

The stated accuracy of the equipment used for the CEC testing should be well within the preferred maximum uncertainty. It should be noted that in order to achieve an ac power efficiency uncertainty of under $\pm 1\%$, individual readings of ac and dc power must be below the preferred maximum uncertainty shown in Table 5.1. A detailed uncertainty analysis is not required for the CEC testing, but the accuracy of the test equipment must be verified, for example with the use of known current and voltage standards. A discussion of the methods used to ensure compliance with overall measurement uncertainty requirement.

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.

The ambient air measurement should not be impacted directly by the operating temperature of or air flow from the inverter. Rooms are preferred to environmental chambers since less air movement is necessary to maintain consistent air temperature. The reason for limiting air movement to a minimum is to keep from biasing the cooling

effectiveness of passively cooled inverters, where even small air flows can drastically affect unit performance. Humidity is not specifically called out in the test protocol. However, when elevating a typical indoor space to 40°C, the relative humidity will generally fall to below 50%. If relative humidity of the test area is above 50% under 40°C ambient conditions, it is likely that moisture is being added to the air to skew the test results. Humidity of the test area should be reported for the Maximum Continuous Output Test, and no moisture should be added to the air to improve heat transfer.

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

5.2.1 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

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 $\pm 5\%$ 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. The array must be configured to minimize inductive loops and must be protected according to NEC requirements.

5.2.2 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 power factor $(\text{Inverter Rated Output Power})/(\text{Inverter Output Current at Rated Power})$ 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 60 Hz
- 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 $\pm 5\%$ 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 $\pm 50\%$ 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

◎◎**Maximum Continuous Output Power.** Section 5.4 shall be performed in its entirety for test condition A of Table 5 -2 with the following exceptions: 1) the test shall be performed at an ambient temperature of 40 °C, rather than 45 °C, and 2) the dc Vnom may be selected by the manufacturer at any point between $V_{min} + 0.25*(V_{max}-V_{min})$ and $V_{min} + 0.75*(V_{max}-V_{min})$. It is not necessary to perform Section 5.4 for test conditions B through E of Table 5-2.

5.4 Maximum Continuous Output Power

This test will establish the maximum output power level that the unit can maintain for a period of not less than 180 minutes at the unit's rated maximum ambient operating temperature after reaching thermal equilibrium.

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, lighted flamingo statues, 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".

Paragraphs 2 and 3 of this section are intended to ensure that the inverter under test is representative of a fully-loaded unit in an actual installation. Ancillary equipment should be designed to operate in whatever environment is required (e.g. display is indoor or indoor/outdoor).

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.

Since the efficiency testing required by the CEC includes three dc voltages and only one ac voltage (nominal), if an inverter is listed for operation at more than one nominal ac voltage, it must be evaluated separately for each nominal voltage level.

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 Section 5.5.

Prior to performing the test, the unit shall be stored at $45\pm 5^{\circ}\text{C}$ ($113\pm 9^{\circ}\text{F}$) 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.

In order to bring the inverter to thermal equilibrium more quickly under the powered test, and to address the thermal stabilization of the more massive components, like magnetics, that may not be directly monitored for temperature, the protocol requires that the inverter be stored at 45°C for a minimum of 24 hours immediately preceding testing. If this is done at the customer’s facility prior to the arrival of the representatives of the NRTL witnessing the tests, heat sink temperature data shall be provided to the NRTL showing that the unit was exposed to 45°C for the necessary duration. It is the NRTL’s decision whether or not to accept this data as credible or restart the heat soak under their control.

Table 2-2 Maximum Continuous Output Power Test Conditions

Test	V _{dc}	V _{ac}	Maximum Power
A	V _{nom}	V _{nom}	
B	V _{max}	V _{nom}	
C	V _{min}	V _{nom}	
D	V _{min}	102% V _{min}	
E	V _{max}	98% V _{max}	

Notes:

- Test done at nominal frequency (50 Hz or 60 Hz) ±0.1Hz.
- 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.
- V_{nom} = For ac, this is the manufacturer specified nominal ac operating voltage. For dc, use the average of V_{min} and V_{max}.
- V_{min} = 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.
- V_{max} = 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).
- 102% of V_{min} and 98% of V_{max} conditions are selected to provide performance at low and high voltages while avoiding tripping the unit because of minor fluctuations in ac line voltage. Tests may need to be performed to verify the actual ac voltage trip settings prior to performing this test (see, for example, Draft IEEE P1547.1).

The CEC stipulations in Appendix 3 E state that only Test A from Table 5-2 needs to be performed (therefore test step 13 need not be run in section 5.4.1). This means that the maximum continuous power test need only be run at nominal dc and ac voltages. It also stipulates that the dc V_{nom} need not be the average of V_{max} and V_{min}, but it must be between V_{min}+0.25*(V_{max}-V_{min}) and V_{min}+0.75*(V_{max}-V_{min}). Therefore this test cannot be done near either voltage extreme on the dc side of the inverter. Another difference between the CEC requirements and the test protocol is that the maximum continuous power test need only be run at 40°C regardless of the manufacturer’s stated maximum operating temperature. However, the heat soak is still done at 45°C.

5.4.1. Test Procedure

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.

- 1) Adjust the test environment air temperature to the manufacturer's stated maximum operating temperature $\pm 3^{\circ}\text{C}$.
- 2) Connect the UUT according to the instructions and specifications provided by the manufacturer to the selected input and output power sources.
- 3) Set all input source parameters to the nominal operating conditions for the UUT.
- 4) Set (or verify) all UUT parameters to the nominal operating settings.
- 5) Set the UUT (including the input source as necessary) to provide 100% of its rated output power.
- 6) Record all applicable settings.
- 7) Set the UUT to operate at the manufacturer's stated maximum output power level.
- 8) Set the input source to provide the power level necessary to achieve the desired output power level and at the input voltage defined in Test A in Table 2-2.
- 9) Set the simulated utility to provide the ac voltage defined in Test A in Table 2-2.
- 10) Allow the unit to operate for at least 150 minutes and until the heat sink temperature stabilizes
- 11) 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):
 - Input voltage (dc and ac)
 - Input current (dc and ac)
 - Input power (average dc + ac RMS)
 - Output voltage (ac)
 - Output power (ac)
 - Ambient temperature ($^{\circ}\text{C}$)
 - Inverter temperature at heat sink ($^{\circ}\text{C}$).
- 12) 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 10 for heating that has already occurred.
- 13) Repeat steps 8)-12) for Test Conditions B through E in Table 2-2. If tests are run consecutively, the 150 minute temperature soak in step 10 may be skipped.

Step 5 of 5.4.1 states that the inverter should be set at rated power. The intent is there are no firmware changes or settings that limit or expand the unit's maximum power. The unit will be tested as received with no limits removed allowing the unit to disregard thermal safeties or power foldback requirements imposed by the listing.

Input power should be the average power integrated over many cycles (usually 5 seconds or more). For completeness, record Output current (ac) along with the other items in step 11 since it is normally recorded by power analyzers.

5.4.2 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 in Table 2-2

- **AC Output Power** (minimum of the 5-minute averages or sampled values)

The unit **Maximum Continuous Output Power** will be stated as minimum of the 5 values recorded in Table 2-2.

For temperatures below the maximum ambient operating temperature, values shall be reported as Reduced Temperature Continuous Output Power (XX °C).

Conversion Efficiency. Section 5.5 shall be performed for test conditions A, B and C of Table 5.3, subject to the following: 1) the tests shall be performed with dc V_{nom} equaling the same voltage as selected above for the Maximum Continuous Power Output test, 2) steps 1 through 8 of the test procedure (Section 5.5.1) shall be performed at 25 °C, and not at 45 °C, and 3) to reduce time for each test condition, begin at the highest power level and go to the lower power levels. If done in this order it will only be necessary to wait for temperature stabilization at the 100 percent power level. In addition, the unit only needs to be operated at full output power for one hour, rather than 2.5 hours, and no preheating is necessary if the Conversion Efficiency test is performed within 1 hour of full operation under test 5.4, provided the unit has not been exposed to ambient temperature of less than 22 °C.

5.4 Conversion Efficiency

This evaluation 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 array power, array voltage, utility voltage, and ambient temperature.

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, lighted flamingo statues, 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.

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 record results that occur with the unit in a power foldback mode. When power foldback occurs, mark “Foldback” in the recording sheet and note that foldback has occurred along with the details of the situation.

Table 2-3 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.

As a result of the meeting on February 25, it was decided that disabling the MPPT was not appropriate since this can alter the true operation of the inverter and provide erroneous efficiency performance data. The dc power supply must be capable of operating the inverter in as stable a manner as possible, and the measurement equipment must be set to gather data at a high enough sampling rate and over a sufficient averaging interval so that the data are not affected by the variations caused by MPPT operation. Similar considerations should be made for anti-islanding operation as necessary.

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).

Table 2-3 Efficiency Test Conditions

Test	V _{dc}	V _{ac}	Inverter DC Input Power Level						
			100%	75%	50%	30%	20%	10%	5%
A	V _{nom}	V _{nom}							
B	V _{max}	V _{nom}							
C	V _{min}	V _{nom}							
D	V _{min}	102% V _{min}							
E	V _{max}	98% V _{max}							

Notes:

- 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. V_{nom}: For ac, this is the manufacturer specified nominal ac operating voltage. For dc, use the average of V_{min} and V_{max}.
- e. V_{min}: 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. V_{max}: 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. 102% of V_{min} and 98% of V_{max} conditions are selected to provide performance at low and high voltages while avoiding tripping the unit due to minor fluctuations in ac line voltage. Tests may need to be performed to verify the actual ac voltage trip settings prior to performing this test (see, for example, Draft 6 IEEE P1547.1).
- h. If, for any given test, the percentage change in efficiency between the 50% and 100% power levels is less than 2%, the test at 75% may be omitted.

- i. The test at 5% of rated power is optional and is provided for consistency with other standard reporting methods (see Table 2-5).
- j. Allowable tolerance on input power level is as follows:

Table 2-4 Power Tolerance

Power	Tolerance	Power	Tolerance
5%:	3% - 7%	50%:	45% - 55%
10%:	8% - 10%	75%:	70% - 80%
20%:	18% - 22%	100*%:	95% - 105%
30%:	27.5% - 32.5%		

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

5.5.1 Test Procedure

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.

- 1) Adjust the test environment air temperature to 25°C ±3°C.
- 2) 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. Allow the unit to operate for at least 150 minutes to bring electronic circuits and components up to a stable operating temperature
- 3) Adjust the input source operating voltage (Vdc) to the Test “A” level shown in Table 2-3
- 4) Adjust the output source operating voltage (Vac) to the level Test “A” shown in Table 2-3. Adjust the output source frequency to nominal.
- 5) Adjust the input source power to the first Test “A” level shown (100%) in Table 2-3.
- 6) 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):
 - Input voltage (dc and ac)
 - Input current (dc and ac)
 - Input power (average dc + ac RMS)
 - Output voltage (ac)
 - Output power (ac)
 - Ambient temperature (°C)
 - Inverter temperature at heat sink.

Input power should be the average power integrated over many cycles (usually 5 seconds or more). For completeness, record Output current (ac) along with the other items in step 6 since it is normally recorded by power analyzers.

- 7) Repeat steps 4)-5) for the remaining Test "A" power levels shown in Table 2-3. If tests are run consecutively, the 150 minute temperature soak in step 10 may be skipped.
- 8) Repeat steps 2)-6) for Test conditions B through E in Table 2-3. Temperature stabilization may be better facilitated by doing all of the tests (A-E) at one power level, then changing to the next power level. Either way, tests should be done from highest power level to the lowest.
- 9) Adjust the ambient temperature to $45 \pm 3^{\circ}\text{C}$ and repeat steps 2)-7).
- 10) Repeat steps 1) –8) 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.

The intent of step 10 is to ensure at least 5 sets of data from the 7 or more sets obtained in step 6 after outliers are removed..

Alternatively, the UUT may be connected to a PV array of suitable voltage and monitored over a clear day with points representing the conditions listed in Table 2-3 extracted from the collected data. PV modules will have to be added to or removed from series strings to provide the prescribed array voltages.

5.5.2 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

- Average DC Input Power (average of five sampled values)
- Average AC Output Power (average of five sampled values)
- Efficiency = Average AC Output Power/Average DC Input Power. These are the values to be entered into Table 2-3.

All recorded data should be included in the report. Electronic submission of the raw data is acceptable.

The unit Peak Efficiency will be stated as the maximum of the 25 averaged efficiency values recorded in Table 2-3.

The unit Nominal Average Efficiency will be stated as the average of the nine efficiency values calculated for the 50%, 75%, and 100% input power levels for tests A, B, and C (designated by the shaded area in Table 2-3).

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

$$\eta_{wid} = F_1\eta_5 + F_2\eta_{10} + F_3\eta_{20} + F_4\eta_{30} + F_5\eta_{50} + F_6\eta_{75} + F_7\eta_{100}$$

where

$\eta_5, \eta_{10}, \eta_{20}$, etc. - measured efficiency values at 5%, 10%, 20%, etc. of rated power, recorded in Test A, Table 2-3, above.

F_1, F_2, F_3 , etc. - the weighting factors defined in Table 2-5 below:

Table 2-5 Weighting factors for calculating Weighted Efficiency

Factor	Inverter Power Level	Weighting Factor	
		High-Insolation ^[1]	Low-Insolation ^[2]
F_1	5%	0.00	0.03
F_2	10%	0.04	0.06
F_3	20%	0.05	0.13
F_4	30%	0.12	0.10
F_5	50%	0.21	0.48
F_6	75%	0.53	0.00
F_7	100%	0.05	0.20

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

As stated at the end of Appendix 3E, the 5% inverter power level is not tested and receives a 0% weighting factor in the High-Insolation weighting factor category above. Final calculations are to be done using the provided spread sheet for standardization in data reporting.

Tare Losses. Section 5.7.1 shall be performed in its entirety. It is not necessary to perform the tests under Section 5.7.2 or Section 5.7.3.

5.7 Tare Losses

This series of tests determines the utility ac power required to operate the unit in standby mode (nighttime Tare losses) as well as the dc input power levels at which the unit starts up and shuts down. 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)

5.7.1 Test Procedure - Tare Level

- 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
- 3) Increase the simulated array voltage only (simulated array current and power remains at zero) to the inverter minimum array operating voltage.
- 4) Record the power level to or from the simulated utility
- 5) Increase the input voltage only (simulated array current and power remains at zero) to the mid point of the inverter input operating voltage range.
- 6) Record the power level to or from the simulated utility
- 7) Increase the input voltage only (simulated array current and power remains at zero) to the maximum of the allowable input voltage range.
- 8) Record the power level to or from the simulated utility
- 9) Adjust the input voltage only (simulated array current and power remains at zero) to the mid point of the inverter input operating voltage range.
- 10) Increase simulated array current level in steps of 0.1% of rated current. Hold at each current level for 5 seconds or otherwise long enough to ensure the unit is not able to successfully start up.
- 11) Record the input power level just below which the unit successfully transitions from standby to normal operation.

12) Continue to increase the input current level in steps of 0.1% of rated power until the output power rises just above zero (output \geq 1% of input) and record that value of input current and input power.

Section 5.7.1 is intended to characterize the losses of the inverter at various stages of its operation: during sleep mode at night (if applicable), through startup, to fully operating. Every inverter is slightly different so this procedure will have to be adjusted to fit the requirements of the individual inverter. Some inverters power their controls from the ac side (as assumed in the procedure) while others power their controls from the dc side. Depending on how the controls are powered, small non-zero current may flow from the array before the unit begins to process power. The most important factor is tested in step 2 of this section (the nighttime power loss). This is the value that will be provided as public information on the CEC website. Section 5.7.4 states that only certain values are reported, however, for the purposes of the CEC testing, recorded means reported for section 5.7.1.

Please note that the tests for Power Foldback (Section 5.8) and Inverter Performance Factor/Inverter Yield (Section 5.9) are NOT required. The data and reports resulting from the tests for Maximum Continuous Output Power (Section 5.4), Conversion Efficiency (Section 5.5) and Tare Losses (Section 5.7.1) must be provided to the Energy Commission and will be made public. The inverter tested must utilize the same hardware and software configuration evaluated during the UL 1741 certification test.

Note also that the MPPT test (section 5.6) is not required.

The methodology for rating inverters on the Energy Commission list is based on the weighted inverter efficiency measured at various load points. Weighting inverter efficiency will be determined with the following weighting factors:

DC Input Power Level	Weighting Factor
10%	0.04
20%	0.05
30%	0.12
50%	0.21
75%	0.53
100%	0.05

The above table is from the high insolation column of Table 5.4 of the Sandia Protocol.

The Energy Commission also plans to review if changes should include adjusting the ratings for inverters with battery-backup to account for losses inherent in battery backup systems.

At this time, , the efficiency of inverters incorporating battery-backup systems shall be measured from the battery terminals on the inverter through to the ac output with all ancillary ac equipment included. This is a testing simplification that is meant to bypass any input charge controllers that may be integral or ancillary to a battery-backup system. The three dc voltages used for the inverter efficiency test should be: (1) the minimum operating voltage (usually around 44 Volts on a 48-Volt inverter); (2) the maximum operating voltage (usually around 60 Volts on a 48-Volt inverter); and, (3) a typical nominal operating battery voltage mentioned in the product literature (51-54 Volts for a 48-Volt inverter).

2.2 Additional Items Discussed at the February 25 Meeting

2.2.1 Testing at the manufacturer's facility

Witness testing was a major discussion during the course of the meeting. The case was made that given the April 1 deadline that the only way the majority of inverters could be certified would be if they were tested at the manufacturer's facilities. The NRTL must verify that the unit under test is a representative sample (hardware, software, configuration, accessories, etc.) and that the manufacturer-supplied test equipment is accurate and otherwise suitable for these tests.

- 1.) The product and key components within it shall be verified against the listing report. In cases where these tests are done by a NRTL other than the one who did the listing and the listing report is not available to the testing NRTL, a product description report will need to be written. This product description report will be compared to the listing report by the CEC and shall include the following:
 - a. Firmware revision number
 - b. Checksum and processor model
 - c. Model , Serial number, and Date of Manufacture
 - d. List of optional components not covered in model # (configuration as tested, e.g., external xfmr)
 - e. List of parts (critical components), magnetics, storage components (capacitors, filters, etc...), switching devices, etc., including model number

- f. Heat sink sizes, part number, material, coating
 - g. Enclosure description
 - h. Weight of unit
 - i. Internal and external pictures
- 2.) The NRTL should perform a power quality test on the unit at full power and at the three dc input voltages to make sure the inverter is operating within proper power quality parameters and has not been tampered with to produce better power or efficiency results.
- 3.) Test Report
- a. Must have listing report or all items listed in 1) above.
 - b. Must have a complete description of test apparatus
 - i. Power analyzer or DAS
 - ii. Make, model, cal date, for all major components
 - iii. Description and results of Spot check to verify equipment accuracy. (e.g., inject a known voltage or current). Report stated accuracy of test equipment.
 - iv. Temperature measuring devices—Verify with known device.
 - v. Test and record harmonics: full power %; high and low dc voltage, as noted in 2) above.
 - vi. Air flow (no additional air movement—not in wash of HVAC registers)
 - vii. Lead lengths and wire gauges to ensure no significant error or transducer burdens.
 - c. Must have Excel document filled out completely (attached)
 - d. Electronic files with raw recorded data from testing.
 - e. Test conditions (e.g. temperature, relative humidity, etc...)
- 4.) Beware of noise impacting measuring devices particularly if device has not been tested for FCC compliance.