Chapter 5
Test Procedures for Photovoltaic Inverters, DC Fluorescent Lights, and PV Systems

In this chapter, the test procedures for PV balance of system (BOS) components and PV systems are continued from the previous chapter. Specifically, this chapter describes the test procedures for PV inverters, DC fluorescent lights, and PV systems.

5.1 Photovoltaic Inverters

Like charge controllers, international standards (IEC and PV GAP) currently do not exist for inverters. Also IEEE, ASTM, and NEC standards are currently not available.

5.1.1 Tests for Verification of Stand-Alone Inverter Specifications

Since international and national standards for PV inverters are not yet established, this subsection describes the test procedure for verification of specifications of inverters used for stand-alone PV systems. These specifications were also developed for the project assisted by the World Bank–Global Environment Facility involving procurement of Solar Home Systems, and are applicable to inverters for small PV systems, that is, 1 kWp or less. The items for testing PV inverters are listed in Table 5.1, followed by description of the test method for each item.

1. Appearance and documentation

a. Appearance

Technical requirements: No physical damage (including damage from shipping and handling), carton damage, moisture penetration, and loose components.

Test method: Visually inspect the inverter for any physical damage, including damage from shipping and handling. Also check the inverter for carton damage, moisture penetration, and loose components.

b. Labels

Technical requirements: Clear labels with the following information:

- Manufacturer name and model.
- Serial number.
- Input and output voltage and current ratings.
- Battery and load connection points and polarity.
Test method: Visually check inverter to verify that all the labels listed under technical requirements are included, and that they indicate the connection points and polarity of the battery and load.

c. Documentation

Technical requirements: The following documentation should be included:

Test method: Check to be sure all documents listed under technical requirements are included with the inverter.

2. Efficiency versus power level

Technical requirements: Inverter efficiency should be higher than 80 percent, when the output power level is above 75 percent of the rated power level.

Test method: Using the test set-up with a variable resistive load as shown in figure 5.1, measure the inverter efficiency as

\[
\eta = \frac{\text{AC Power Output}}{\text{DC Power Input}} = \frac{W_{ac}}{V_{dc}I_{dc}}
\]

Increase the AC power output from 10 percent to 100 percent of the rated power to obtain the plot of inverter efficiency versus output power. The inverter efficiency should be higher than 80 percent for all output power levels above 75 percent of the nominal power.

3. Load (output power) capability

Technical requirements: The inverter can operate safely at an ambient temperature of 25°C for at least (a) four hours at full rated output power, (b) one minute at 125 percent of the rated output power, and (c) two seconds at 150 percent of the rated output power (to simulate high-surge currents because of starting of motors).

Test method: Using the test set-up as shown in figure 5.1 at 25°C ambient temperature, adjust the load to provide full rated output power and

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Table 5.1
Stand-Alone PV Inverter Test Items
maintain this power level for four hours. The inverter should operate safely and not reach temperatures high enough to result in fire, to damage any materials used, or to activate the operation of any protective device. Repeat this test at 125 percent of the rated output power for one minute, and then at 150 percent of the rated output power for two seconds. Verify the inverter's safe operation under both of these conditions as done previously (at rated power for four hours).

4. Input voltage range and frequency verification

Technical requirements:
(a) The inverter should operate normally when the input DC voltage is in the range of 90–120 percent of the nominal input voltage. During the normal operation of the inverter, its AC output voltage must remain in the range of 220 volts ± 10%.
(b) Inverter output operating frequency should be in the range of 50 Hz ± 5%.

Test method: Using the test set-up as shown in figure 5.1, keep the output power constant at half rated power and vary the input DC voltage from 90 percent to 120 percent of the nominal input voltage, while also measuring the inverter output frequency with an oscilloscope or a meter placed across the shunt (figure 5.2). Repeat this test at different output power levels ranging from 10 percent to 100 percent of the rated power. For all power levels, the inverter should meet the technical requirements, as described for items 4 and 5.
5. Voltage harmonics

Technical requirements: For a sine-wave inverter, the maximum total harmonic distortion in the output voltage should not exceed 5 percent of the fundamental component at the full rated output power of the inverter.

Test method: This test should be conducted only for sine-wave inverters. Using a harmonic analyzer, measure the total harmonic distortion in the output voltage at different power levels. At any power level it should not exceed 5 percent of the fundamental component at the full rated power.

6. Noise

Technical requirements: Audio noise produced by the inverter should be less than 65 dB at a distance of 3 meters, when the inverter is operating.

Test method: Measure the inverter noise at a distance of 3 meters from the inverter at half and full rated power, and verify that it is below 65 dB.

7. Quiescent current

Technical requirements: Inverter self-consumption current should not exceed 3 percent of the rated input current.

Test method: Using the test set-up as shown in figure 5.1 and, with the load disconnected, measure the DC input current drawn by the inverter at different DC input voltages from 90 percent to 120 percent of the nominal input voltage. Verify that the current drawn at no load is within 3 percent of rated input current for all conditions.

8. Vibration durability

Technical requirements: No damage is caused to the inverter by the vibrations, tested in the range of 10–55 Hz, 0.35 mm, 3-axis direction for 30 minutes.

Test method: Subject the inverter to vibrations as stated in the technical requirements. Check the inverter to verify that no mechanical damage or malfunction has occurred.

9. Protection functions

a. Low-voltage protection

Technical requirements: Inverter should shut down automatically to protect the battery when the input voltage is lower than 90 percent of the rated value (1.8 volts per battery cell).

Test method: Start with the DC power supply voltage at the inverter nominal input voltage, and gradually decrease the power supply voltage. Check whether the inverter shuts down automatically when its input voltage falls below 90 percent of the rated value.

b. Output overcurrent protection

Technical requirements: Inverter should shut down automatically if the output power exceeds 150 percent of the rated power.

Test method: Using the test set-up as shown in figure 5.1, adjust the load
to provide the full rated AC power. Then increase the load gradually, and verify that the inverter stops operating as the load increases above 150 percent of the rated power.

c. Short circuit protection

Technical requirements: If the inverter output is shorted, a circuit breaker in the inverter output circuit should trip or a fuse should blow to protect the inverter from any damage.

Test method: Using the test set-up as shown in figure 5.1, short the inverter AC output by reducing the variable load resistance to zero, or remove the load and short the inverter output terminals. The circuit breaker should trip or the fuse should blow, but no damage to the inverter or other hazard should occur.

d. Reverse polarity protection

Technical requirements: If the polarity of the inverter DC input connections is reversed, the inverter should not get damaged.

Test method: With the DC power supply voltage output adjusted to its minimum, connect the output terminals of the power supply in reverse polarity to the inverter DC input. Then, increase the power supply voltage gradually to the nominal input voltage of the inverter, and maintain this voltage for at least one hour. Verify that no damage to the inverter or power supply occurs.

e. Lighting protection

Technical requirements: The inverter should have protection to avoid damage from lightning (required only in the area of excessive lightning). 

Test method: Visually check the type and rating of the surge arrestors to ensure that they are capable of absorbing expected surge energy from lightning at the location of the inverter.

5.1.2 PV Inverter Standards

At present there are no internationally approved PV inverter standards, either by IEC or recommended by PV GAP. Working Group 6 (WG6) of IEC Technical Committee 82 (TC 82) is drafting IEC standards for PV inverters as listed below. A well-written, technically proficient, and sufficiently detailed PV inverter charge controller standard has been drafted and approved by the UL of the United States. This standard, UL 1741, primarily specifies the test procedure for safety of charge controllers and inverters, and is also listed below.

IEC Inverter Standards (Work in Progress)

* Lightning protection is optional for low lightning areas.
5.2 DC Fluorescent Lights

The international standards (IEC and PV GAP) for PV-powered DC fluorescent lights do not exist at present. Also IEEE, ASTM, and NEC standards are currently not available.

This subsection describes the test procedure for verification of specifications of DC fluorescent lights used for stand-alone PV systems. These specifications were also developed for the project assisted by the World Bank–Global Environment Facility involving procurement of solar home systems, and they are applicable to DC-powered fluorescent lights for stand-alone PV systems.

The test items for DC fluorescent lights are listed in table 5.2, followed by the test procedures.

1. Appearance and labels
   a. Appearance
      Technical requirements: No physical damage (including damage from shipping and handling), carton damage, moisture penetration, and loose components.
      Test method: Visually inspect the fluorescent light for any physical damage, including damage from shipping and handling. Also check the carton for damage, moisture penetration, and loose components.

   b. Labels
      Technical requirements: Clear labels with the following information:
      - Manufacturer name and model number.
      - Serial number.
      - Voltage and wattage ratings.
      - Polarity.
      - Date of manufacture and batch number.
      Test method: Visually inspect the light to verify that all the labels listed under the technical requirements are included, and that they indicate the connection points and polarity. Verify that the labels cannot be removed after being polished by a wet cloth for 15 seconds.

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Table 5.2
DC Fluorescent Lights Test Items

Quality Improvement of Photovoltaic Testing Laboratories in Developing Countries 48
2. Lamp socket and holder

Technical requirements: The socket of the lighting fixture should meet the requirements of the international standard, “Technical Requirements of Lamp Holders for Tubular Fluorescent Lamps and Starter-Holders.” The lamp socket electrical parts should not be exposed during normal operation (that is, hands and fingers should not be able to come in contact with electrical parts of the lamp socket). The size of the socket and holder should meet the requirements of IEC 61 standard.

Test method: Measure the size of the socket and holder with a ruler or other measuring instrument, and verify that they meet the requirements of the standard in IEC 61.

3. Luminous efficiency

Technical requirements:

(a) After 100 hours of conditioning, the luminous efficiency of the fluorescent light should not be less than 35 lumens per watt (L/W) without lamp cover and reflectors at the nominal input voltage of the fluorescent light and an ambient temperature of 25ºC.

(b) The luminous efficiency of the fluorescent light should not be less than 80 percent of its rated value throughout the voltage range of 90–120 percent of the nominal voltage.

Test method:

(a) Using the test set-up as shown in figure 5.3, operate the fluorescent light for 100 hours for normal usage conditioning. Then, with the lamp cover and reflector removed, measure its luminance and the input power required at the nominal voltage and at an ambient temperature of 25ºC, and determine its luminous efficiency as follows:

\[ \text{Efficiency} = \frac{\text{Luminance}}{\text{DC voltage} \times \text{DC current}} \]

The efficiency should be 35 L/W or greater.

(b) Vary the input voltage of the fluorescent light from 80 percent to 130 percent of the nominal voltage, and verify that the luminous efficiency is 80 percent or greater than its rated value for all voltages in the range of 90–120 percent of the nominal voltage.

![Figure 5.3](image-url)
4. Lamp operating voltage
   Technical requirements: Minimum operating voltage when the lamp starts should be at least 90 percent of the nominal voltage, and the lamp should be capable of continuous operation between 90 percent and 120 percent of the nominal voltage.
   Test method: In the previous test for luminous efficiency, also check that the minimum striking voltage at which the lamp will turn on is less than or equal to 90 percent of the nominal voltage, and verify that the maximum voltage for at least four hours of continuous operation without damage to the lamp or fixture is at least 120 percent of the nominal voltage.

5. Minimum operating frequency
   Technical requirements: The minimum operating frequency of the fluorescent lamp should be 20 kHz.
   Test method: Measure the operating frequency at the lamp terminals with an oscilloscope for input voltage to the fixture ranging from 90 percent to 120 percent of its nominal voltage. The frequency should be greater than 20 kHz for all voltage conditions.

6. Electrical waveform and crest factor
   Technical requirements:
   (a) Electrical waveform at the lamp terminals must be symmetrical in time to within 10 percent.
   (b) The maximum crest factor (ratio of peak to root mean square voltage at the lamp terminals) should be no more than 2.0.
   Test method: In the previous test for operating frequency, also record the electrical waveform at the lamp terminals with the oscilloscope, and verify that the waveform is symmetrical within 10 percent and that the crest factor is below 2.0 over the lighting fixture input voltage range of 90–120 percent of the nominal voltage.

7. Protection functions and quiescent current
   a. Lamp open circuit protection
   Technical requirements: The lighting fixture should be protected against damage when operating under open circuit conditions (for example, when the lamp is removed or has failed).
   Test method: Remove the lamp from the socket, and apply the nominal voltage to the fixture. Check the operation for at least four hours to ensure that no damage to the fixture or lamp occurs and that no excessive heat is generated.
   b. Quiescent current
   Technical requirements: The current drawn by the fluorescent light when operating with a failed or removed lamp should be limited to less than 20 percent of the nominal current consumption of the light.
   Test method: Measure the current drawn by the fluorescent light with the lamp removed. It should be less than 20 percent of the nominal current consumption. If possible, repeat this test with a failed lamp in the socket.
The current drawn should be limited to 20 percent of the nominal current consumption. After the test, the lighting fixture should operate normally.

c. Reverse polarity protection

Technical requirements: The lighting fixture and lamp should be protected against reverse polarity, or the fluorescent light as a whole should be protected from damage if reverse polarity is applied.

Test method: Using the test set-up as shown in the figure, adjust the regulated power supply to the nominal voltage of the fluorescent light. Connect the lighting fixture terminals to the power supply in reverse polarity for one hour, and verify that no damage occurs to the lamp, lighting fixture, or power supply.

8. Vibration durability

Technical requirements: No damage is caused to the fixture or the lamp by the vibrations, tested in the range of 10–55 Hz, 0.35mm, 3-axis directions for 30 minutes.

Test method: Put the fluorescent light to vibrations of 10–55 Hz, 0.35 mm, at 3-axis directions for 30 minutes. Then check that no mechanical damage or malfunction has occurred to the fixture or the lamp.

9. Lamp lifetime

Technical requirements: Fluorescent lights must provide a minimum lamp lifetime of 1,000 hours. The switching lifetime (ON-OFF cycles) of the lamp must be at least 1,000 cycles.

Test method: Operate the fluorescent light with a DC power supply for 1,000 hours, during which the power supply voltage should be automatically varied between 90 percent and 120 percent of the nominal voltage of the light. During each hour, the lamp should be automatically turned off for a brief period (one minute or less) to simulate ON-OFF cycling of the lamp. No failure of the lamp should occur during 1,000 hours of operation.

10. Insulation resistance

Technical requirements: For the fluorescent lamps with metal covers, the insulation resistance between the cover and the lamp terminals should meet IEC 598-1 requirements.

Test method: For the fluorescent lamps with metal casings, measure the insulation resistance between the metal casing and the lamp terminals at about 1,000 volts with a high-pot tester. The insulation resistance value should comply with the standard in IEC 598-1.

11. Fire and pressure resistance

a. Fire test

Technical requirements: Insulation materials should comply with heat and fire resistance requirements. After the fire test, the self-burning time of
the insulation material should not exceed 30 seconds. Any flame should burn out within 30 seconds after the fire source is removed. A thin paper under the insulation material should not burn by fallen burning debris from the insulation material.

Test method: Put fire for 10 seconds at the place where the highest temperature is most likely to occur in the insulation material during operation, and verify that the flame on the insulation material burns out within 30 seconds after the removal of the fire source. Also, check that a thin paper under the insulation material does not burn from the fallen debris of the insulation material. (For the insulation material of the lights, use a 650° heated fiber to test its fire and heat resistance.)

b. Ball pressing test

Technical requirements: After ball pressing test, the mark should be less than 2 mm.

Test method: Press the insulation material with a steel ball (5 mm in diameter) with 20 N pressure. Check the press mark one hour after the test, and verify that the mark is smaller than 2 mm.

### 5.3 Photovoltaic Systems

It is recommended that the laboratories planning to conduct testing of PV systems to meet the needs of a fast-growing domestic market or broad-based government and international programs adopt international standards, including IEC standards and PV GAP recommended standards. The existing IEC standards are listed here, and a hard copy of each of the published IEC PV standard is included in Appendix 4 of this manual. PV GAP–recommended standard PV RS-1 is also listed below and included in Appendix 3.

The U.S. PV system test standards are drafted by the Standards Coordinating Committee 21 for Photovoltaics (SCC 21) of IEEE and approved by the IEEE Standards Board. These standards are also very rigorous and comparable to IEC standards in their quality, effectiveness, and detail. They are listed here for consideration of being adopted by the testing laboratory, especially when the international standards on the particular test subject are not yet available.

### IEC Systems Standards


Quality Improvement of Photovoltaic Testing Laboratories in Developing Countries
10. IEC 62124, Ed. 1.0: PV Stand-Alone Systems—Design Qualification and Type Approval, Draft.

PV GAP Systems Standards

Institute of Electrical and Electronics Engineers Systems Standards

NEC Systems Standards