IEEE Standards

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IEEE Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems

IEEE Standards Coordinating Committee 21

Sponsored by the
IEEE Standards Coordinating Committee 21 on
Fuel Cells, Photovoltaics, Dispersed Generation,
and Energy Storage (SCC21)



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IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage (SCC21)

Approved 11 September 2003

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Abstract: Tests to determine the performance of stand-alone photovoltaic (PV) systems and for verifying PV system design are presented in this recommended practice. These tests apply only to complete systems with a defined load. Performance testing is conducted outdoors under prevailing conditions over a period of about one month. The tests are intended to assist designers, manufacturers, system integrators, system users, and laboratories that will conduct the tests. System safety and component reliability issues are not addressed in this recommended practice.
Keywords: design verification, performance testing, stand-alone photovoltaic (PV) system

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Introduction

(This introduction is not part of IEEE Std 1526-2003, IEEE Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems.)

The majority of performance problems in stand-alone photovoltaic (PV) systems tend to fall into one of three areas:

1) Poor design or selection of inferior or inappropriate components by the system designer
2) Poor installation of the PV system by untrained or inexperienced system installers
3) Improper use or lack of maintenance of the PV system by the user

The purpose of this recommended practice is to address Item 1). In many cases, PV systems provide energy to a load as well as to a battery storage system, which powers the load at night or other times when the PV array output is insufficient. In such cases, an evaluation of system performance is heavily based on how well the PV array charges the battery and how well the battery is sized for the load.

This standard provides test methods and procedures for assessing the performance of stand-alone PV systems that include PV modules, charge controller, batteries, and loads. This standard provides type testing on a system level that can be performed at a test laboratory or by qualified personnel in the field with the appropriate test equipment. These tests are intended to evaluate the adequacy of the system design and performance claims. They require about one month to complete.

Participants

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1. Overview

In many cases, photovoltaic (PV) systems provide energy to a load as well as to a battery storage system that powers the load at night or other times when the PV array output is insufficient. In such cases, an evaluation of system performance is based on how well the PV array charges the battery and how well the battery is sized for the load.

This recommended practice provides test methods and procedures for assessing the performance of stand-alone PV systems that include PV modules, charge controller, batteries, and loads. This recommended practice provides type testing on a system level that can be performed at a test laboratory or by qualified personnel in the field with the appropriate test equipment. These tests are intended to evaluate the adequacy of the system design and performance claims. They require about one month to complete.

1.1 Scope

The test methods and procedures included in this recommended practice cover stand-alone PV systems. Procedures provided are for conducting performance testing of individual components and complete systems. The methodology includes testing the system outdoors in prevailing conditions and indoors under simulated conditions.

1.2 Purpose

This recommended practice provides test methods and procedures for determining stand-alone PV system performance and conducting design verification. Test procedures provided in this recommended practice are intended to assist designers, manufacturers, system integrators, users, and laboratories in conducting these performance tests.

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1.3 Limitations

These tests do not address component or system reliability, quality issues, or compliance to a regional or national mechanical or electrical code, e.g., National Electrical Code® (NEC®)(NFPA 70-2002) [B10].[1] These tests do not cover PV systems connected to an electric utility distribution system. These tests only apply to packaged stand-alone PV systems with a defined load. Test results are only relevant to the system tested. If the PV system or load changes in any way, then the tests must be rerun on the modified system. A packaged stand-alone PV system includes all components with a specified load and a specified load profile.

It may be desired to run performance tests on the load(s). Such tests may be found in other documents. Sources listed in Annex A describe in detail how to test a lamp in a PV lighting system. Such tests, however, are beyond the scope of this recommended practice and may require specialized test equipment and procedures.

This recommended practice does not address issues of safety. It is the responsibility of the user of this recommended practice to establish appropriate safety and health practices.

2. Definitions

For purposes of this recommended practice, the following terms and definitions apply. *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition [B7], should be referenced for terms not defined in this clause.

2.1 array to load (A:L) ratio: The PV array ampere-hour (Ah) to load Ah ratio is the monthly daily average PV Ah available divided by the monthly daily average load Ah. Average daily PV Ah are calculated by taking the average daily solar resource for each month in kWh/m^2 times the PV array current at its maximum power point (I_{mp}) at standard test conditions (STC). A:L ratios can also be calculated in terms of their respective watthour parameters.

NOTE—See IEEE Std 1361™-2003 [B9].

2.2 charge controller: An electrical control device that regulates battery charging by voltage control and/or other means. The charge controller may also incorporate one or more of the following functions: discharge termination, regulation voltage temperature compensation, load control, and status indication.

NOTE—See IEEE Std 1361-2003 [B9].

2.3 design month: The month in which the daily A:L ratio is minimum. The design month is typically either the month with the least solar insolation or the month with the greatest load.

2.4 hours of autonomy: The length of time that the PV system can provide energy to the load without energy from the PV array.

2.5 low-voltage disconnect (LVD): The battery voltage at which the load is disconnected to prevent over discharge.

NOTE—See IEEE Std 1361-2003 [B9].

2.6 low-voltage reconnect (LVR): The battery voltage at which the load is reconnected after an LVD.

NOTE—See IEEE Std 1361-2003 [B9].

[1]The numbers in brackets correspond to the numbers of the bibliography in Annex A.

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2.7 plane-of-array (POA) irradiance: The sunlight intensity per unit area (power) measured in the same plane as the PV array in W/m^2.

2.8 solar insolation: The total daily solar irradiance in kWh/m^2. Most solar insolation data for a geographic location is reported for each month as the average daily irradiance for a specific array tilt angle. Typical daily solar insolation values are between 2 kWh/m^2 and 7 kWh/m^2.

NOTE—See IEEE Std 1361-2003 [B9].

2.9 standard test conditions (STC): The accepted conditions under which PV devices are commonly rated: 1000 W/m^2 irradiance at a spectral distribution of airmass (AM) 1.5 and a 25 °C PV cell temperature.

NOTE—See ASTM E1036M-1996 [B1].

2.10 sun hour (Sh): A term commonly used instead of solar insolation. One Sh is equivalent to a solar insolation of 1 kWh/m^2.

2.11 usable battery capacity (UBC): The measured capacity in Ah that a battery will deliver to the load before reaching LVD.

3. Testing methodology

3.1 Testing overview

This recommended practice describes the procedures to test stand-alone PV systems for overall system functionality. The required test specimens are described in 3.2. The documentation that will be generated by the tests is described in 3.3. Clause 4 covers the system inspection and documentation review, as well as the PV system hardware inspection. Clause 5 covers the installation and instrumentation of the PV system. The PV system performance tests are found in Clause 6. The specific sequence of tests is determined based on the specific system and its loads. Clause 7 is a final system inspection, examining the system maintenance procedures and looking for visible hardware problems. An optional PV array current-voltage characteristic (I-V) curve is discussed in Clause 8. The system data analysis is discussed in Clause 9. A sample system summary is provided in Annex B.

3.2 PV system and test requirements

The tests in this recommended practice require at least one complete system. A “complete” system includes the system documentation and all related parts for installation. This includes, but is not limited to, PV modules, array wiring, the charge controller, the battery, the inverter, and all loads used in the system. Spare or optional parts need to be included if they are recommended by the system manufacturer. The location/environment/climate where the system is intended to be installed and operated (not necessarily the test location) shall be specified.

The manufacturer shall specify the load, how many hours per day the load is designed to run, what time of day the load is designed to operate, and what solar insolation is required to meet the load requirements. The system cannot be tested without this information as the tests evaluate how well the system meets these performance claims.

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3.3 Test report and documentation

In addition to a complete system summary, the test report should include all relevant test data, calculations, and appropriate comments. An electronic copy of the system data should be kept for future reference. The test report will include an expected and actual load profile.

4. System inspection

4.1 System documentation review

NOTE—Underlined items are to be included in the system summary.

It is important that the system summary be as complete as possible. Record the date that the system arrived at the test site. Review all system documentation provided and attach a copy of all the documentation to the system summary. Note how the load is controlled. Record the location/environment/climate for which the system is designed, and how the test site conditions compare to the conditions the system was designed for. Because of the sensitivity of lead-acid battery capacity to temperature, the battery should be operated in a temperature range similar to that of the expected location. Record the hours of autonomy, and Sh to battery recovery specified by the system manufacturer. Record the system and component specifications. If the system includes an inverter, it will be considered part of the direct current (dc) load.

The following relevant documents should be included with a PV system:

- Design drawings and calculations.
- An overview of all major system components and principles of operation.
- A complete parts list, including all electrical components, mechanical hardware, and other equipment required for installing the system. The list should include a complete description for each piece of equipment.
- A diagram indicating the proposed layout of the entire system.
- Electrical schematics and diagrams showing all major components and devices, including conductor types and sizes, connections of individual modules and array source circuits, terminations at junction boxes, and connections to surge suppression devices.
- Mechanical drawings showing details of system and array mechanical support.
- Warranty information on individual components.
- Specifications and manuals for each component.
- Complete assembly and installation instructions for assembling and wiring the PV system.
- Procedures for commissioning, operating, disconnecting, servicing, and maintaining the complete PV system and individual components.
- Safety documentation for the system and its components.

Although it is recommended to obtain general design documents and technical specifications prior to system purchase/installation, these documents should also be part of the documentation package given to the system owner/operator upon system commissioning. It is imperative that system designers, installers, end users, and other relevant parties understand the system operation and maintenance issues or have access to the information.

Lack of comprehensive system information may lead to poor system performance. Often system operators may not understand system issues that can be easily remedied. Some of these issues may include array losses due to soiling or shading, battery limitations due to improper system use, charge-current losses due to loose

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or disconnected interconnects, etc. These potential problems may be avoided if the end users have access to the complete documentation package and if they are properly trained in the operation of the PV system.

4.2 Initial system hardware inspection

Visually inspect system parts and components and verify that they arrived undamaged. Note any damage, especially that which could affect system performance or safety. Replace any damaged items that could affect the system performance or safety. Verify that all parts listed in the parts list are present. Note all missing, damaged, or replaced parts in the system summary. Tests should not proceed if it is determined during this inspection or at any other time that the system may be dangerous to install or operate.

5. Data acquisition system (DAS) and PV system installation

5.1 DAS specifications and installation

The performance tests require the use of a data logger with input ranges that will accommodate the expected output ranges of each measurement sensor. Appropriate voltage dividers or shunts may be used. The data logger input impedance should be greater than 1 megohm and otherwise be compatible with each sensor or signal conditioning unit. The operating temperature ranges for all DAS equipment should be compatible with the environment where they will be used. The data sampling interval should be no greater than 10 seconds. Data should be stored as 5 minute averages with minimums and maximums as specified in Clause 6. Note the DAS data sampling interval and data recording period in the system summary. The DAS must be reliable: If any critical data is lost due to a DAS failure during any test, that test must be restarted. Any DAS failures shall be noted. Table 1 and the following subclauses summarize the system parameters to be measured. For systems in which the load is not automatically controlled, relays controlled by the DAS will be required to turn the load on and off.

Table 1—System parameters to be measured

Measured parameter	Symbol	Comments	Other recorded parameters
Array voltage	V_pv	—	—
Load voltage	V_ld	—	Minimum, average, and maximum
Battery voltage	V_bt	Measured at the battery	Minimum, average, and maximum
Array current	I_pv	—	—
Load current	I_ld	—	Minimum, average, and maximum
Battery current	I_bt	—	Battery Ah
Ambient temperature	T_amb	—	—
Battery temperature	T_bt	At temperature compensation sensor or at negative battery post	Minimum, average, and maximum
Solar irradiance	Irr_poa	Measured in same plane as array	Solar insolation
Load operation	Ld_Op	—	Load run time

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5.1.1 Voltage measurements

The voltage sensors should have a range exceeding the maximum expected voltages. The voltage measurement accuracy should be within ± 1% of the maximum expected measurement. Install voltage sensors for the PV array and loads. In systems where the load runs only at night (for example, lighting), monitoring the array and load voltages separately is optional. The battery voltage shall be monitored at the battery terminals.

5.1.2 Current measurements

The current sensors should have a range exceeding the expected maximum positive and negative currents. The current measurement accuracy should be within ± 1% of the maximum expected measurement. Install current sensors for the PV array, battery, and loads. The DAS shall monitor the current into and out of the battery. In systems where the load runs only at night (for example, lighting), monitoring the array and load currents separately is optional. Current into the battery (from the PV array) will be considered positive, and current out of the battery (to the load) will be considered negative.

Special measurement techniques or equipment may be required to accurately measure the current and Ah in PV systems that utilize pulse width modulated (PWM) controllers. The controller type and its switching frequency should be determined. Appropriate current measurement equipment should be utilized.

5.1.3 Temperature measurements

The temperature sensors should have a range exceeding the expected maximum positive and negative temperatures. The accuracy of temperature measurements should be within ± 2 °C of the maximum expected measurement. The ambient air temperature measurement should use an appropriate ventilated radiation shield mounted in a location that will indicate the environment in which the system is operating. The battery temperature sensor should be mounted as close as possible to the charge controller's temperature-compensation sensor or at the negative battery terminal if there is no temperature compensation sensor.

5.1.4 Irradiance measurements

The irradiance sensor should have a range exceeding the maximum expected irradiance and an accuracy of ± 5%. The irradiance sensor should be as close as possible to the array without shading it. The irradiance sensor should be mounted in the same plane and within ± 5° of the array tilt angle.

5.1.5 Load operation sensor

Install a sensor to detect that load is operating properly (e.g., a light sensor detecting the light output of a lamp). Simply monitoring the load current may be inadequate as, in the case of a fluorescent lamp, the bulb could malfunction yet the ballast may continue to draw current. Note the load operation sensor (e.g., manual switch, automatic photosensor and timer, etc.).

5.1.6 DAS calibration and diagram

After the DAS installation, verify each sensor is calibrated. Note the type and accuracy of each sensor. Note the calibration factor and the date of the last calibration of each sensor, if applicable. Modify a copy of the PV system schematic or diagram to show all DAS sensor locations and include it with the system summary.

5.1.7 DAS control of loads

With some PV systems, the DAS may need to be configured to control the loads. Modify a copy of the PV system schematic or diagram to show the DAS load control and include it with the system summary.

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5.1.8 Data sampling interval and recording period

The sampling interval should be 10 seconds or less. Data should be stored as 5 minute averages with minimums and maximums as specified in Clause 6. Note the DAS data sampling interval and data recording period in the system summary. All data shall be time-stamped showing the date and time when each record is recorded. The clock shall be maintained to within 60 seconds of local standard time. Use of daylight saving time may confuse later evaluation of the data and is not recommended.

5.1.9 Data records

The DAS records the measurements as described in Table 2.

Table 2—Sample data record format

Parameter	Avg	Max	Min	Sample	Count
Date and time	—	—	—	X	—
System ID[a]	—	—	—	X	—
V_{PV}	X	—	—	—	—
V_{LD}	X	X	X	—	—
V_{BT}	X	X	X	—	—
I_{PV}	X	—	—	—	—
I_{LD}	X	X	X	—	—
I_{BT}	X	X	—	—	—
T_{AMB}	X	—	—	—	—
T_{BT}	X	—	—	—	—
Irr_{POA}	X	—	—	—	—
LD_{OP}	X[b]	—	—	—	—
Samples	—	—	—	—	X[c]

NOTES
1—Data stored in 5-minute records.
2—Order of fields may be different than shown.
3—Additional parameters may be recorded as desired.

[a]An alphanumeric ID uniquely identifying the system under test.
[b]Each LD_{OP} sample is converted, real time, into 1.0 if the load is operating or 0.0 if it is not. The resulting average will indicate the fraction of the recording interval that the load was operating.
[c]Number of samples in the record.

5.2 PV system installation

Install the system according to the manufacturer's instructions. The PV system installation instructions should cover all steps of the system assembly. The system should be installed according to the installation instructions, and the system should not be modified or added to, except as necessary to perform the measurements described in this recommended practice. Minor system modifications may be unavoidable to install the DAS. Any system modifications should be noted in the system schematic or diagram to be included in

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the system summary. If cabling is precut and terminated for system installation, the full length of cable should be used.

If the controller set points are adjustable, use the set points recommended by the system manufacturer. If this information is not provided, use the set points as received.

6. System performance tests

The system performance tests will do the following:

a) Ensure the system and load operate as expected
b) Ensure the PV array is capable of recharging the battery
c) Determine any significant change in the usable battery capacity
d) Determine the system's hours of autonomy
e) Verify the manufacturer's specifications

It should take about one month to complete the tests.

Figure 1 is a graphical example of the performance tests in terms of battery voltage and time. The tests may be conducted outdoors or indoors with a solar simulator and temperature chamber. Refer to IEC 62124 [B6] for indoor tests. The test conditions should be similar to climatic conditions where the system will be deployed. The time periods shown are only approximate. Each test, briefly described below, is fully described in the subclause in parentheses.

Initial functional test (FT_I)—Verify the system and load operate properly (6.2).

Initial usable battery capacity test (UBC_I)—Discharge the battery to measure the usable battery capacity (6.3).

Initial recovery test (RT_I)—Determine the ability of the PV system to recharge the discharged battery (6.4).

Final functional test (FT_F)—Verify the system and load operate properly (6.5).

Final recovery test (RT_F)—Determine the ability of the PV system to recharge the discharged battery (6.6).

Final usable battery capacity test (UBC_F)—Discharge the battery to measure the usable battery capacity (6.7).

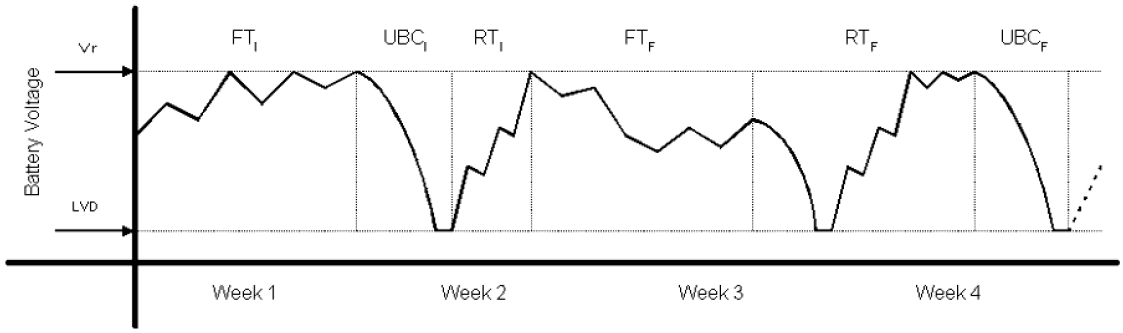


Figure 1—Sample test procedure profile

If the system or load fail to operate during any of the tests, the entire test sequence described in this clause will have to be rerun before the system can pass the performance tests.

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6.1 Battery preparation

Prior to beginning the system tests, follow the manufacturer's instructions for charging the battery; if no instructions are provided, begin the tests with the battery as received. Note in the system summary if the system documentation instructs the user when and how to charge the battery.

6.2 Initial functional test (FT_I)

This test verifies that the system and load operate as intended and the battery is charged prior to UBC_I. The duration of the test period should be at least 7 days.

After installing the PV system, verify that the load starts and operates properly. In systems with multiple loads, verify that all loads can operate simultaneously and that each individual load can start and run while all other loads are operating. For this test, it is only necessary to operate the loads long enough to determine that they function correctly. Configure loads for normal operation after verifying they operate.

Record the start date and time in the system summary. Operate the system and load as recommended by the system manufacturer. Verify that the system and DAS function correctly. Record the daily number of hours the load is set to operate in the system summary.

For only that time when the load is operating, calculate and record: the minimum, average, and maximum load voltages; the minimum, average, and maximum load currents; and the load run time. For the entire FT_I, calculate and record: the daily POA insolation; the maximum and minimum battery voltages; and the minimum, average, and maximum battery temperatures. Record the maximum battery voltage as the regulation voltage (V_r). Record the average battery temperature while the battery is at V_r. Record the end date and time.

6.3 Initial usable battery capacity test (UBC_I)

The UBC_I test establishes a baseline usable battery capacity. UBC_I will be used to determine if the PV system's battery capacity changes significantly after running the tests.

The battery should reach V_r for 3 consecutive days before starting UBC_I. During a period when the battery is at V_r, disconnect or cover the array. Record the start date and time. Operate the full load continuously, 24 hours per day, until it discharges the battery to LVD. Verify that the system and DAS function correctly. Some systems may require special measures in order to run the load continuously down to LVD. In systems with no LVD, operate the load until it stops functioning properly. Allow the system to remain in the LVD state for a minimum of 5 hours and up to a maximum of 12 hours; doing so should identify if the hysteresis between LVD and LVR is adequate. If the hysteresis is too small, the load may rapidly turn on and off. Record the minimum measured battery voltage as the LVD. Calculate and record the Ah withdrawn from the battery as the UBC_I. Calculate and record the average battery temperature. Record the end date and time.

6.4 Initial recovery test (RT_I)

The purpose of the recovery test is to determine how many Sh are required for the array to bring the discharged battery to V_r with the load operating normally.

The battery must be at LVD before starting this test. Record the start date and time. Operate the system and load normally as recommended by the system manufacturer. Verify that the system and DAS function correctly. This test should run until the controller just reaches V_r. The load may not turn on the first few days until the battery voltage rises above the LVR set point. Calculate and record the Sh to V_r. Record the end date and time.

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NOTE—Sh are used to simplify the explanation of Ah production of the array. One Sh is equivalent to one hour of sunlight at an intensity equal to the reference irradiance, two hours of sun at half the reference irradiance, etc. Thus, it is intended to provide an estimate of the amount of time the system operates at its rated output.

For example, suppose the daily insolation is 5 kWh/m^2 on an array with a rated current of 3 A at 1000W/m^2 (1kW/m^2). From this, Sh is calculated as follows:

$$\frac{5\,\mathrm{kWh/m^2}}{1\,\mathrm{kW/m^2}} = 5\mathrm{h}$$

The estimated array's daily Ah production would then be 5 h × 3 A, or 15 Ah. In using Sh, it is assumed that the array voltage is high enough to charge the battery; this assumption is confirmed while conducting the tests.

6.5 Final functional test (FT_F)

This test verifies that the system and load operate as intended. The test period should be at least 7 days.

6.5.1 FT_F normal system operation

Operate the system and load normally as recommended by the system manufacturer. Record the daily number of hours the load is set to operate. Operate the system and load for at least 7 days. Verify that the system and DAS function correctly. At least 2 consecutive days should be "low" insolation, less than 2 kWh/m^2 per day. At least 2 days, not necessarily consecutive days, should be "high" insolation, greater than 5 kWh/m^2 per day. The average daily insolation should be about 4 kWh/m^2 per day.

Record the start date and time. For only that time when the load is operating during the functional test, calculate and record: the minimum, average, and maximum load voltages; the minimum, average, and maximum load currents; and the load run time. For the entire FT_F, calculate and record: the daily POA insolation; the maximum and minimum battery voltages; and the minimum, average, and maximum battery temperatures. Record the end date and time.

6.5.2 Computed A:L ratio

The A:L ratio is an indicator of the ability of the system to supply power to the load. The expected A:L ratio is computed from manufacturers' ratings and historical insolation data for the test site. Compute and record this A:L ratio as shown in Equation (1):

$$\text{Computed A:L ratio} = \frac{\text{Array current} \times \text{estimated Sh}}{\text{Load current} \times \text{daily run time}} \quad (1)$$

where

Array current (A)	is the specified STC array current at maximum power,
Estimated Sh (h)	is the manufacturer's estimated average daily insolation during the month(s) the test is conducted divided by the reference irradiance (typically 1000 W/m^2 or 1 kW/m^2),
Load current (A)	is the name-plate rated current of the load,
Daily run time (h)	is the number of hours the load is set to operate each day.

6.5.3 Measured A:L ratio

The actual A:L ratio is computed using the values measured during the FT_F. Calculate and record this as shown in Equation (2):

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$$\text{Measured A:L ratio} = \frac{\text{Ah from the array}}{\text{Ah to the load}} \quad (2)$$

where

Ah from the array (Ah) is the number of Ah going into the battery in 6.5.1,
Ah to the load (Ah) is the number of Ah withdrawn from the battery in 6.5.1.

6.6 Final recovery test (RT_F)

The purpose of the recovery test is to determine how many Sh are required for the array to bring the discharged battery to V_r with the load configured for normal operation.

6.6.1 RT_F battery discharge cycle

Prior to conducting the RT_F, the battery must be discharged to LVD. Disconnect or cover the array. Operate the full load continuously, 24 hours per day, until it discharges the battery to LVD. Verify that the system and DAS function correctly. Some systems may require special measures in order to run the load continuously down to LVD. In systems with no LVD, operate the load until it stops functioning properly.

6.6.2 RT_F normal system operation

The battery must be at LVD before starting this test. Record the start date and time. Operate the system and load normally as recommended by the system manufacturer. Verify that the system and DAS function correctly. This test should run until the controller reaches V_r, 3 consecutive days before starting UBC_F. The load may not turn on the first few days until the battery voltage rises above the LVR set point. Calculate and record the Sh to V_r and the battery Ah to V_r. Record the maximum battery voltage as V_r. Calculate and record the average battery temperature while the battery remains at V_r. Record the end date and time.

6.7 Final usable battery capacity test (UBC_F)

This test will determine the UBC_F. The purpose of UBC_F is to determine how much the PV system's UBC has changed after running the tests and to determine the hours of system autonomy.

6.7.1 UBC_F battery discharge cycle

During a period when the battery is at V_r, disconnect or cover the array. Record the start date and time. Operate the full load continuously, 24 hours per day, until it discharges the battery to the LVD voltage level. Verify that the system and DAS function correctly. Some systems may require special measures in order to run the load continuously down to LVD. Record the minimum measured battery voltage as the LVD. Calculate and record the Ah withdrawn from the battery as the UBC_F. Calculate and record the average battery temperature. Record the end date and time.

6.7.2 Compare UBC

Calculate and record the difference between the initial and final measured UBC as shown in Equation (3):

$$\text{Change in capacity} = UBC_I - UBC_F \quad (3)$$

where

UBC_I (Ah) is the Ah capacity of the battery measured in 6.3,
UBC_F (Ah) is the Ah capacity of the battery measured in 6.7.1.

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If the capacity loss is significant (greater than 10%), then it is best to review the battery selection and battery charging parameters to identify a possible cause for the capacity loss.

It is possible for the UBC to increase in subsequent battery charge/discharge cycles. If the UBC increases between subsequent tests, note this in the system summary.

6.7.3 Compute hours of autonomy

Calculate and record the hours of autonomy. The hours of autonomy value indicates how long the system may operate the load during periods of low solar irradiance. Compute and record this as shown in Equation (4):

$$\text{Hours of autonomy} = \frac{\text{UBC}_F}{\text{Load current}} \quad (4)$$

where

UBC_F (Ah) is the Ah capacity of the battery measured in 6.7.1,

Load current (A) is the average daily load current measured in 6.5.1.

If the battery temperature during the testing is significantly different from the expected temperature at the system deployment site, the battery manufacturer should be consulted to find out what effect temperature has on UBC_F. Note the temperature effect in the system summary.

6.8 Final battery charge

Upon completion of UBC_F, the battery should be charged as recommended by the manufacturer. Doing so will minimize permanent degradation of the battery capacity.

The performance measurement tests are complete.

7. Final system inspection

7.1 System maintenance procedure review

Read through and perform the manufacturer's recommended system maintenance procedures. Note if the maintenance procedures are clear and report any difficulties that occur in performing the maintenance, for example, having to disconnect and remove the battery in order to check the battery electrolyte level.

7.2 Visual inspection

Record the date testing ends. Visually inspect the system, noting any problems or damage. Inspect all major system components: the PV array; the load; the mounting structure; wiring and cable; fuses, disconnects, and protection devices; the controller; and the battery.

7.3 Wiring inspection

Flex all conductors along their entire length, noting any discoloration or brittleness of the insulation. Undersized conductors and poor connections will tend to overheat, leading to brittle and discolored insulation.

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8. Array I-V curve (optional)

After the system has been operating outdoors for several weeks, an I-V curve of the array may be swept. An I-V curve shall be swept if the array has a front shield or any obstructions that would shade the array within 3 hours before or after solar noon. Disconnect the array from the system. Attach an I-V curve tracer or variable resistor to the dc terminals of the array. Clean the array and then sweep a curve on a clear, sunny day and when the POA irradiance is between 800 W/m^2 and 1100 W/m^2. Record the following measured array information, normalized to the appropriate rating conditions (e.g., STC: 1000W/m^2 and a PV cell temperature of 25 °C): P_{max}, I_{sc}, V_{oc}, V_{pp}, and I_{pp}.

9. System pass/fail test criteria

The system performance tests should verify the manufacturer's specifications for the operation of the PV system and load. The system passes the performance tests if the four conditions in 9.1, 9.2, 9.3, and 9.4 are met.

9.1 System and load operation

The system and load operated every day as they were supposed to, with the load operating the length of time specified by the system integrator.

9.2 PV array

The PV array recharged the battery as specified by the system integrator.

NOTE—The system should be able to charge the battery to regulation voltage (V_r) and remain at V_r, as specified by the *system integrator*. The system may be unable to charge the battery to V_r if the solar insolation at the test site is lower than normal or lower than designed for, or if the ambient temperature is too high. If the load fails to operate, the ability of the PV array to charge the battery should be computed from the system integrator-supplied A:L ratio. If the load fails to operate and the system integrator does not supply A:L information, the system will have failed the performance tests.

9.3 Minimum UBC

The minimum UBC and system's hours of autonomy remained at or above the values specified by the system integrator.

NOTE—If the battery temperature at the test site is different from the temperature at the location where the PV system is expected to be deployed, the measured battery capacity could be different from the rated capacity due to the temperature difference. The capacity of lead-acid batteries will typically be decreased at lower temperatures. The system integrator should provide battery capacity temperature adjustment information. If the system failed to meet the specified UBC or hours of autonomy, or the system integrator does not provide the battery capacity temperature adjustment information, the system will have failed the performance tests.

9.4 Change in usable battery capacity

The decrease in usable battery capacity, $UBC_I - UBC_F$, is less than 10%.

NOTE—If the capacity loss is significant (greater than 10%), then it is best to review the battery selection parameters and battery charging parameters to identify a possible cause for the capacity loss (see IEEE Std 1361-2003 [B9]).

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Annex A

(informative)

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[2]ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (http://www.astm.org/).

[3]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[5]The NEC is published by the National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, USA (http://www.nfpa.org/). Copies are also available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

[6]NREL publications are available from National Renewable Energy Laboratory, Publications Department, 1617 Cole Blvd., Golden, CO 80401-3393, USA, tel. +1 303 275 3000 (http://www.nrel.gov/publications).

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Annex B

(informative)

Sample system summary

For each PV system tested, a system summary should be completed at the test laboratory and submitted to the person requesting the tests. In general, information entered in the “Specified” column is information provided by the system or component manufacturers and information in the “Measured/observed” column is information gathered or calculated, during the system tests. Depending upon the specific system to be tested, not all items in the summary will have entries. The corresponding test procedure subclause number is listed in each entry box. In addition to the completed system summary, the following items should also be provided to the person requesting the tests: copies of all documentation provided with the system and a modified copy of the system schematic or diagram to show the DAS sensor locations. Supporting test data, along with appropriate comments, may also be attached and submitted as necessary or requested as part of the system summary. A sample system summary is shown in Table B.1 and Table B.2.

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Table B.1—Stand-alone PV system summary—Page 1 of 2— System specifications and information

System information		
Parameter		
System manufacturer/model	4.1	**Test ID:**
Vendor	4.1	
Test site	4.1	
System inspection		
System arrival date	4.1	
(Attach copy of system documentation)	4.1	
Damaged parts?	4.2	
All parts present?	4.2	
System installation & instrumentation		
Battery preparation documented?	6.1	
Load(s) start & operate	6.2	
Data sampling interval and recording period	5.1.8	
(Attach diagram with DAS sensor locations)	5.1.6	
Array information		
Parameter	**Specified**	**Measured/observed**
Module manufacturer	4.1	
Module model	4.1	
Active material	4.1	
Array configuration (series and parallel)	4.1	
Array tilt and orientation	4.1	
Array P_{max} @ STC	4.1	Clause 8
Array V_{pp}	4.1	Clause 8
Array I_{pp}	4.1	Clause 8
Array V_{oc}	4.1	Clause 8
Array I_{sc}	4.1	Clause 8
Array shield	4.1	
Load information		
Parameter		
Description	4.1	
Manufacturer	4.1	
Number of loads	4.1	
Voltage	4.1	6.5.1
Current	4.1	6.5.1
Power	4.1	
Operating temperature range	4.1	
Controller information		
Parameter		
Manufacturer	4.1	
Model	4.1	
Type	4.1	
V_r set point	4.1	6.6.2
Controller-battery compatibility	4.1	
Temperature compensation Sensor attaches to battery	4.1	
Reverse-current protection	4.1	
Load timer accuracy	4.1	6.5.1
LVD set point	4.1	6.5.1
Battery information		
Parameter		
Manufacturer	4.1	
Model	4.1	
Type	4.1	
Configuration (series and parallel)	4.1	
Voltage	4.1	
Capacity	4.1	6.7.1

Documentation checklist			
Parameter		**Included**	**Notes/comments**
Parts list	4.1		
Required-but-not-included-parts list	4.1		
Recommended-tool list	4.1		
Mechanical drawings	4.1		
Electrical schematic or diagram	4.1		
Installation procedures	4.1		
Spare parts list	4.1		
Maintenance procedures	4.1		
Troubleshooting guide	4.1		
Array specifications/literature	4.1		
Load specifications/literature	4.1		
Controller specifications/literature	4.1		
Safety documentation	4.1		
Battery specifications/literature	4.1		

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Table B.2—Stand-alone PV system summary—Page 2 of 2—Test information and results

Test information		
Parameter		
System manufacturer/model	4.1	**Test ID:**
Test site	4.1	
Address	4.1	
Contact	4.1	
System operation		
Parameter	**Specified/calculated**	**Measured/observed**
Run time	4.1	6.5.1
Load control method	4.1	
System intended location	4.1	
Intended location design month	4.1	
System performance results		
Parameter		
Hours of autonomy	4.1	6.7.3
Sh to V_r	4.1	6.6.2
A:L ratio	6.5.2	6.5.3
$UBC_I - UBC_F$		6.7.2
System performance tests		
FT_I		**Comments**
Start date & time	6.2	
V_ld min/avg/max	6.2	
I_ld min/avg/max	6.2	
Run time	6.2	
V_bt min/max	6.2	
T_bt min/avg/max	6.2	
V_r	6.2	
T_bt at V_r	6.2	
End date & time	6.2	
UBC_I		
Start date & time	6.3	
LVD	6.3	
UBC_I	6.3	
T_bt at LVD	6.3	
End date & time	6.3	
RT_I		
Start date & time	6.4	
Sh to V_r	6.4	
Battery Ah to V_r	6.4	
End date & time	6.4	
FT_F		
Start date & time	6.5.1	
V_ld min/avg/max	6.5.1	
I_ld min/avg/max	6.5.1	
Run time	6.5.1	
V_bt min/max	6.5.1	
T_bt min/avg/max	6.5.1	
V_r	6.5.1	
T_bt at V_r	6.5.1	
End date & time	6.5.1	
A:L ratio	6.5.2	6.5.3
RT_F		
Start date & time	6.6.2	
V_r	6.6.2	
T_bt at V_r	6.6.2	
Sh to V_r	6.6.2	
Battery Ah to V_r	6.6.2	
End date & time	6.6.2	
UBC_F		
Start date & time	6.7.1	
LVD	6.7.1	
UBC_F	6.7.1	
T_bt at LVD	6.7.1	
End date & time	6.7.1	
$UBC_I - UBC_F$	6.7.2	
Hours of Autonomy	6.7.2	
Final system inspection		
Maintenance procedures ok?	7.1	
System visual inspection ok?	7.2	
System wiring ok?	7.3	
System pass/fail test criteria		
System and load operate as specified?	9.1	
PV array able to recharge battery?	9.2	
UBC meets specifications?	9.3	
$UBC_I - UBC_F < 10\%$	9.4	
System passed or failed?	Clause 9	
If system failed, reason:		

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