

INTERNATIONAL STANDARD

NORME INTERNATIONALE



**Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance –
Part 1: Grid connected systems – Documentation, commissioning tests and inspection**

**Systèmes photovoltaïques (PV) – Exigences pour les essais, la documentation et la maintenance –
Partie 1: Systèmes connectés au réseau électrique – Documentation, essais de mise en service et examen**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**PHOTOVOLTAIC (PV) SYSTEMS – REQUIREMENTS FOR TESTING,
DOCUMENTATION AND MAINTENANCE –****Part 1: Grid connected systems – Documentation,
commissioning tests and inspection**

FOREWORD

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International Standard IEC 62446-1 has been prepared by IEC technical committee 82: Solar photovoltaic energy systems.

This first edition cancels and replaces IEC 62446 published in 2009. This edition constitutes a technical revision.

This edition includes the following significant technical change with respect to IEC 62446:2009:

- the scope has been expanded to include a wider range of system test and inspection regimes to encompass larger and more complex PV systems.

The text of this standard is based on the following documents:

FDIS	Report on voting
82/1036/FDIS	82/1056A/RVD

Full information on the voting for the approval of this standard can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts in the IEC 62446 series, published under the general title *Photovoltaic (PV) systems – Requirements for testing, documentation and maintenance*, can be found on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC website under "<http://webstore.iec.ch>" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
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- amended.

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INTRODUCTION

Grid connected PV systems are expected to have a lifetime of decades, with maintenance or modifications likely at some point over this period. Building or electrical works in the vicinity of the PV array are very likely, for example roof works adjacent to the array or modifications (structural or electrical) to a home that has a PV system. The ownership of a system may also change over time, particularly for systems mounted on buildings. Only by the provision of adequate documentation at the outset can the long term performance and safety of the PV system and works, on or adjacent to the PV system, be ensured.

This part of IEC 62446 is split into two sections:

- **System documentation requirements** – This section details the information that shall be provided within the documentation provided to the customer following installation of a grid connected PV system.
- **Verification** – This section provides the information expected to be provided following initial (or periodic) verification of an installed system. It includes requirements for inspection and testing.

This part of IEC 62446 references IEC TS 62548:2013, which is in the process of being converted into an International Standard. It is envisaged that work on the second edition of IEC 62446-1 will start when IEC 62548 is completed.

PHOTOVOLTAIC (PV) SYSTEMS – REQUIREMENTS FOR TESTING, DOCUMENTATION AND MAINTENANCE –

Part 1: Grid connected systems – Documentation, commissioning tests and inspection

1 Scope

This part of IEC 62446 defines the information and documentation required to be handed over to a customer following the installation of a grid connected PV system. It also describes the commissioning tests, inspection criteria and documentation expected to verify the safe installation and correct operation of the system. It can also be used for periodic retesting.

This part of IEC 62446 is written for grid connected PV systems that do not utilize energy storage (e.g. batteries) or hybrid systems.

This part of IEC 62446 is for use by system designers and installers of grid connected solar PV systems as a template to provide effective documentation to a customer. By detailing the expected commissioning tests and inspection criteria, it is also intended to assist in the verification/inspection of a grid connected PV system after installation and for subsequent re-inspection, maintenance or modifications.

This part of IEC 62446 defines the different test regimes expected for different solar PV system types to ensure that the test regime applied is appropriate to the scale, type and complexity of the system in question.

NOTE This part of IEC 62446 does not address CPV (concentrating PV) systems, however many of the parts may apply.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60364-6, *Low-voltage electrical installations – Part 6: Verification*

IEC TS 62548:2013, *Photovoltaic (PV) arrays – Design requirements*

IEC 61730 (all parts), *Photovoltaic (PV) module safety qualification*

IEC 61557 (all parts), *Electrical safety in low voltage distribution systems up to 1 000 V a.c. and 1 500 V d.c. – Equipment for testing, measuring or monitoring of protective measures*

IEC 61010 (all parts), *Safety requirements for electrical equipment for measurement, control, and laboratory use*

3 Terms and definitions

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

3.1**AC module**

PV module with an integrated inverter in which the electrical terminals are AC only

3.2**cable type**

description of a cable to enable its rating and suitability for a particular use or environment to be determined

Note 1 to entry: In many countries this is done via a code number (eg "H07RNF").

3.3**data sheet**

basic product description and specification

Note 1 to entry: Typically one or two pages. Not a full product manual.

3.4**inspection**

examination of an electrical installation using all the senses in order to ascertain correct selection and proper erection of electrical equipment

3.5**inverter**

electric energy converter that changes direct electric current to single-phase or polyphase alternating current

3.6**micro inverter**

small inverter designed to be connected directly to one or two PV modules.

Note 1 to entry: A micro inverter will normally connect directly to the factory fitted module leads and be fixed to the module frame or mounted immediately adjacent to the module.

3.7**module integrated electronics**

any electronic device fitted to a PV module intended to provide control, monitoring or power conversion functions

Note 1 to entry: Module integrated electronics may be factory fitted or assembled on site.

3.8**PV array**

assembly of electrically interconnected PV modules, PV strings or PV sub-arrays.

3.9**PV cell**

most elementary device that exhibits the photovoltaic effect, i.e the direct non-thermal conversion of radiant energy into electrical energy

3.10**PV module**

smallest complete environmentally protected assembly of interconnected PV cells

3.11**PV string**

circuit of one or more series-connected PV modules

3.12

PV string combiner box

junction box where PV strings are connected which may also contain overcurrent protection devices, electronics and/or switch-disconnectors

3.13

$I_{MOD_MAX_OCPR}$

PV module maximum overcurrent protection rating determined by IEC 61730-2

Note 1 to entry: This is often specified by module manufacturers as the maximum series fuse rating.

3.14

reporting

recording of the results of inspection and testing

3.15

testing

implementation of measures in an electrical installation by means of which its effectiveness is proved

Note 1 to entry: It includes ascertaining values by means of appropriate measuring instruments, said values not being detectable by inspection.

3.16

verification

all measures by means of which compliance of the electrical installation to the relevant standards is checked

Note 1 to entry: It comprises inspection, testing and reporting.

4 System documentation requirements

4.1 General

The purpose of Clause 4 is to list the minimum documentation that should be provided following the installation of a grid connected PV system. This information will ensure key system data is readily available to a customer, inspector or maintenance engineer. The documentation includes basic system data and the information expected to be provided in the operation and maintenance manual.

4.2 System data

4.2.1 Basic system information

As a minimum, the following basic system information shall be provided. This “nameplate” information would typically be presented on the cover page of the system documentation pack.

- a) Project identification reference (where applicable).
- b) Rated (nameplate) system power (kW DC or kVA AC).
- c) PV modules and inverters – manufacturer, model and quantity.
- d) Installation date.
- e) Commissioning date.
- f) Customer name.
- g) Site address.

4.2.2 System designer information

As a minimum, the following information shall be provided for all bodies responsible for the design of the system. Where more than one company has responsibility for the design of the system, the following information should be provided for all companies together with a description of their role in the project.

- a) System designer, company.
- b) System designer, contact person.
- c) System designer, postal address, telephone number and e-mail address.

4.2.3 System installer information

As a minimum, the following information shall be provided for all bodies responsible for the installation of the system. Where more than one company has responsibility for the installation of the system, the following information should be provided for all companies together with a description of their role in the project.

- a) System installer, company.
- b) System installer, contact person.
- c) System installer, postal address, telephone number and e-mail address.

4.3 Wiring diagram

4.3.1 General

As a minimum, a single line wiring diagram shall be provided. This diagram shall be annotated to include the information detailed in 4.3.2 to 4.3.6.

In general, it is expected that this information will be presented as annotations to the single line wiring diagram. In some circumstances, typically for larger systems where space on the diagram may be limited, this information may be presented in table form.

4.3.2 Array – General specifications

The wiring diagram or system specification shall include the following array design information.

- a) Module type(s).
- b) Total number of modules.
- c) Number of strings.
- d) Number of modules per string.
- e) Identify which strings connect to which inverter.

Where an array is split into sub-arrays, the wiring diagram shall show the array – sub-array design and include all of the above information for each sub-array.

4.3.3 PV string information

The wiring diagram or system specification shall include the following PV string information.

- a) String cable specifications – size and type.
- b) String overcurrent protective device specifications (where fitted) – type and voltage/current ratings.
- c) Blocking diode type (if relevant).

4.3.4 Array electrical details

The wiring diagram or system specification shall include the following array electrical information (where fitted).

- a) Array main cable specifications – size and type.
- b) Array junction box / combiner box locations.
- c) DC switch disconnect, location and rating (voltage / current).
- d) Array overcurrent protective devices – type, location and rating (voltage / current).
- e) Other array electronic protective circuitry (such as arc fault detection), if applicable – type, location and rating.

4.3.5 AC system

The wiring diagram or system specification shall include the following AC system information.

- a) AC isolator location, type and rating.
- b) AC overcurrent protective device location, type and rating.
- c) Residual current device location, type and rating (where fitted).

4.3.6 Earthing and overvoltage protection

The wiring diagram or system specification shall include the following earthing and overvoltage protection information.

- a) Details of all earth / bonding conductors – size and type. Including details of array frame equipotential bonding cable where fitted.
- b) Details of any connections to an existing Lightning Protection System (LPS).
- c) Details of any surge protection device installed (both on AC and DC lines) to include location, type and rating.

4.4 String layout

For systems with three or more strings, a layout drawing of the PV system showing how the array is split and connected into strings shall be provided.

NOTE This is particularly useful for finding faults in larger systems and on building mounted arrays where access to the rear of the modules is difficult.

4.5 Datasheets

As a minimum, datasheets shall be provided for the following system components.

- a) Module datasheet for all types of modules used in system – to the requirements of IEC 61730-1.
- b) Inverter datasheet for all types of inverters used in system.

The provision of datasheets for other significant system components should also be considered.

4.6 Mechanical design information

A data sheet for the array mounting system shall be provided. If the mounting structure was custom engineered, include the relevant documentation.

4.7 Emergency systems

Documentation of any emergency systems associated with the PV system (fire alarms, smoke alarms, etc). This information shall include both operation and design details.

4.8 Operation and maintenance information

Operation and maintenance information shall be provided and shall include, as a minimum, the following items:

- a) Procedures for verifying correct system operation.
- b) A checklist of what to do in case of a system failure.
- c) Emergency shutdown / isolation procedures.
- d) Maintenance and cleaning recommendations (mechanical, civil & electrical) – if any.
- e) Considerations for any future building works related to the PV array (e.g. roof works).
- f) Warranty documentation for PV modules and inverters – to include starting date of warranty and period of warranty.
- g) Documentation on any applicable workmanship or weather-tightness warranties.

4.9 Test results and commissioning data

Copies of all test and commissioning data shall be provided. As a minimum, these shall include the results from the verification tests detailed in Clause 5 of this standard.

5 Verification

5.1 General

Clause 5 provides the requirements for the initial and periodic verification of a grid connected PV electrical installation. It references IEC 60364-6 where appropriate and also details additional requirements or considerations.

Much of the verification of a grid connected PV system should be done with reference to IEC 60364-6, which provides the requirements for initial and periodic verification of any electrical installation.

Every installation of subsystems and components shall be verified with reference to IEC 60364-6 during erection, as far as reasonably practicable, and on completion, before being put into service by the user. Initial verification shall include comparison of the results with relevant criteria to confirm that the requirements of IEC 60364 have been met.

For an addition or alteration to an existing installation, it shall be verified that the addition or alteration complies with IEC 60364 and does not impair the safety of the existing installation.

Initial and periodic verifications shall be made by a skilled person, competent in verification.

NOTE 1 Typical verification test sheets are provided in Annexes A, B and C to this standard.

Initial verification takes place upon completion of a new installation or completion of additions or of alterations to existing installations. Periodic verification shall determine, as far as reasonably practicable, whether the installation and all its constituent equipment remain in a satisfactory condition for use.

For a PV system, the interval between verifications shall be no longer than that required by the AC electrical system that the PV system is connected to.

NOTE 2 In some countries the interval between verifications is stipulated by national regulations.

5.2 Inspection

5.2.1 General

Inspection shall precede testing and shall normally be done prior to energizing the installation. The inspection shall be done to the requirements of IEC 60364-6.

If wiring will not be readily accessible after the installation, wiring may need to be inspected prior to or during installation works.

The following items, specific to grid connected PV systems, shall be included in the inspection.

5.2.2 DC system – General

Inspection of the DC installation shall include at least verification that:

- a) the DC system has been designed, specified and installed to the requirements of IEC 60364 and IEC TS 62548:2013;
- b) the maximum PV array voltage is suitable for the array location (IEC TS 62548:2013 and local codes may dictate that installations above a certain voltage may only be placed in certain locations);
- c) all system components and mounting structures have been selected and erected to withstand the expected external influences such as wind, snow, temperature and corrosion;
- d) roof fixings and cable entries are weatherproof (where applicable).

5.2.3 DC system – Protection against electric shock

Inspection of the DC installation shall include at least verification of the measures in place for protection against electric shock:

- a) Protective measure provided by extra low voltage (SELV / PELV) – yes / no.
- b) Protection by use of class II or equivalent insulation adopted on the DC side – yes / no.
- c) PV string and array cables have been selected and erected so as to minimize the risk of earth faults and short-circuits. Typically achieved by the use of cables with protective and reinforced insulation (often termed “double insulated”) – yes / no.

5.2.4 DC system – Protection against the effects of insulation faults

Inspection of the DC installation shall include at least verification of the measures in place for protection against the effects of insulation faults, including the following:

- a) Galvanic separation in place inside the inverter or on the AC side – yes / no.
- b) Functional earthing of any DC conductor – yes / no.

Knowledge of the galvanic separation and functional earthing arrangements is necessary in order to determine if the measures in place to protect against the effects of insulation faults have been correctly specified.

- c) That a PV Array Earth Insulation Resistance detection and alarm system is installed – to the requirements of IEC TS 62548:2013.

NOTE 1 This is typically provided within the inverter.

- d) That a PV Array Earth Residual Current Monitoring detection and alarm system is installed – to the requirements of IEC TS 62548:2013.

NOTE 2 This is typically provided within the inverter.

5.2.5 DC system – Protection against overcurrent

Inspection of the DC installation shall include at least verification of the measures in place for protection against overcurrent in the DC circuits:

- a) For systems without string overcurrent protective device, verify that:
- $I_{MOD_MAX_OCPR}$ (the module maximum series fuse rating) is greater than the possible reverse current;
 - string cables are sized to accommodate the maximum combined fault current from parallel strings.
- NOTE See IEC TS 62548:2013 for calculation of array reverse currents.
- b) For systems with string overcurrent protective device, verify that:
- the string overcurrent protective devices are fitted and correctly specified to the requirements of IEC TS 62548:2013.
- c) For systems with array / sub-array overcurrent protective devices, verify that:
- the overcurrent protective devices are fitted and correctly specified to the requirements of IEC TS 62548:2013.

The potential for the system inverter(s) to produce a DC back-feed into the PV array circuits shall also be verified. It shall be verified that any back-feed current is lower than both the module maximum fuse rating and the string cable ampere rating.

5.2.6 DC system – Earthing and bonding arrangements

Inspection of the DC installation shall include at least verification that:

- a) where the PV system includes functional earthing of one of the DC conductors, the functional earth connection has been specified and installed to the requirements of IEC TS 62548:2013;
- b) where a PV system has a direct connection to earth on the DC side, a functional earth fault interrupter is provided to the requirements of IEC TS 62548:2013;
- c) array frame bonding arrangements have been specified and installed to the requirements of IEC TS 62548:2013;
- NOTE Local codes may require different bonding arrangements.
- d) where protective earthing and/or equipotential bonding conductors are installed, they are parallel to, and bundled with, the DC cables.

5.2.7 DC system – Protection against the effects of lightning and overvoltage

Inspection of the DC installation shall include at least verification that:

- a) to minimize voltages induced by lightning, the area of all wiring loops has been kept as small as possible;
- b) measures are in place to protect long cables (e.g. screening or the use of surge protective devices, SPDs);
- c) where SPDs are fitted, they have been installed to the requirements of IEC TS 62548:2013.

5.2.8 DC system – Selection and erection of electrical equipment

Inspection of the DC installation shall include at least verification that:

- a) the PV modules are rated for the maximum possible DC system voltage;
- b) all DC components are rated for continuous operation at DC and at the maximum possible DC system voltage and current as defined in IEC TS 62548:2013;

NOTE Inspection of the DC system requires knowledge of the maximum system voltage and current.

- The maximum system voltage is a function of the string / array design, the open circuit voltage (V_{oc}) of the modules and a multiplier to account for temperature and irradiance variations.
 - The maximum possible fault current is a function of the string / array design, the short circuit current (I_{sc}) of the modules and a multiplier to account for temperature and irradiance variations
- c) wiring systems have been selected and erected to withstand the expected external influences such as wind, ice formation, temperature, UV and solar radiation;
- d) means of isolation and disconnection have been provided for the PV array strings and PV sub-arrays – to the requirements of IEC TS 62548:2013;
- e) a DC switch disconnector is fitted to the DC side of the inverter to the requirements of IEC TS 62548:2013;

NOTE IEC 60364-9-1 provides four different methods for providing this switch disconnector. It is expected that the type and location of the switch disconnector be shown on the verification report

- f) if blocking diodes are fitted, their reverse voltage rating is at least $2 \times V_{oc}$ (stc) of the PV string in which they are fitted (see IEC TS 62548:2013);
- g) plug and socket connectors mated together are of the same type and from the same manufacturer and comply with the requirements of IEC TS 62548:2013.

5.2.9 AC system

Inspection of the PV system shall include at least verification that:

- a) a means of isolating the inverter has been provided on the AC side;
- b) all isolation and switching devices have been connected such that PV installation is wired to the “load” side and the public supply to the “source” side;
- c) the inverter operational parameters have been programmed to local regulations;
- d) where an RCD is installed to the AC circuit feeding an inverter, the RCD type has been selected according to the requirements of IEC TS 62548:2013.

NOTE Some inverters require a type B RCD.

5.2.10 Labelling and identification

Inspection of the PV system shall include at least a verification that:

- a) all circuits, protective devices, switches and terminals are suitably labelled to the requirements of IEC 60364 and IEC TS 62548:2013;
- b) all DC junction boxes (PV generator and PV array boxes) carry a warning label indicating that active parts inside the boxes are fed from a PV array and may still be live after isolation from the PV inverter and public supply;
- c) means of isolation on the AC side is clearly labelled;
- d) dual supply warning labels are fitted at point of interconnection;
- e) a single line wiring diagram is displayed on site;
- f) installer details are displayed on site;
- g) shutdown procedures are displayed on site;
- h) emergency procedures are displayed on site (where relevant);
- i) all signs and labels are suitably affixed and durable.

NOTE The requirements for signs and labelling of the PV system are detailed in IEC TS 62548:2013.

5.3 Testing

5.3.1 General

Testing of the electrical installation shall be done according to the requirements of IEC 60364-6.

Measuring instruments and monitoring equipment and methods shall be chosen in accordance with the relevant parts of IEC 61557 and IEC 61010. If other measuring equipment is used, it shall provide an equivalent degree of performance and safety. The test methods described in this standard are given as reference methods; other methods are not precluded, provided they give no less valid results.

Each test shall be performed as described in Clause 6 of this standard.

All tests shall be carried out where relevant and should be made in the sequence listed.

In the event of a test indicating a fault, once that fault has been rectified all previous tests shall be repeated in case the fault influenced the result of these tests.

In the event of any test indicating failure to comply with the requirements, that test and any preceding test that may have been influenced by the fault shall be repeated.

5.3.2 Test regimes and additional tests

The test regime that is applied to a solar PV system needs to be appropriate to the scale, type, location and complexity of the system in question.

This standard defines two test regimes together with a number of additional tests which can also be performed once the standard sequence is completed.

- Category 1 tests – The minimum requirement – A standard set of tests that shall be applied to all systems.
- Category 2 tests – An expanded sequence of tests that assumes all Category 1 tests have already been undertaken.
- Additional tests – Other tests that may be performed in some circumstances.

5.3.3 Test regimes for systems with module level electronics

For systems constructed using AC modules, power optimizers or with any other form of module level electronics, Table 1 shall be used to determine the correct test regime.

Table 1 – Modifications to the test regime for systems with module level electronics

System	Modification to standard test regime
AC Module	• No DC test or inspection works required
Micro inverter <i>No site constructed wiring is used (all connections using module and inverter leads)</i>	• Testing of DC circuits is not required • Inspection of DC works is required
Micro inverter <i>Site constructed wiring is used</i>	• Testing of DC circuits is required • Inspection of DC works is required
Module integrated electronics	• Where possible, a standard test regime to be followed • Manufacturer to be consulted to determine any restrictions to tests (e.g. insulation resistance test) • Manufacturer to be consulted on pass / fail criteria for tests (e.g. expected V_{oc})

Due to the diverse nature of the different module level electronics equipment available, it is not possible to specify what tests can be safely performed or to detail the expected results that may be expected from those tests. In all cases of systems with any form of module level electronics (such as power optimizers), the manufacturer should be consulted prior to commissioning.

5.3.4 Category 1 test regime – All systems

A Category 1 test regime is the minimum test sequence that is expected and shall be applied to all systems irrespective of the system scale, type, location or complexity.

System testing needs to address both the AC and DC sides of the PV system. In general, AC testing should be completed prior to proceeding to DC testing.

In some circumstances, AC side testing may only be practical at a later stage in a project and may need to be scheduled after the DC testing phase. Where this is necessary, some of the DC functional tests (e.g. ensuring correct inverter operation) will need to be postponed until after the AC testing is complete.

The following test regime shall be performed on all systems:

AC side

Tests to all AC circuit(s) to the requirements of IEC 60364-6.

DC side

The following tests shall be carried out on the DC circuit(s) forming the PV array.

- a) Continuity of earthing and/or equipotential bonding conductors, where fitted.
- b) Polarity test.
- c) Combiner box test.
- d) String open circuit voltage test.
- e) String circuit current test (short circuit or operational).
- f) Functional tests.
- g) Insulation resistance of the DC circuits.

NOTE 1 These tests are described in detail in Clause 6.

For reasons of safety and for the prevention of damage to connected equipment, the polarity test and combiner box test must be performed before any strings are interconnected.

An I-V curve test (as described in Clause 6) is an acceptable alternative method to derive the string open circuit voltage (V_{oc}) and short circuit current (I_{sc}). Where an I-V test is performed, separate V_{oc} and I_{sc} tests are not required – provided the I-V curve test is performed at the appropriate stage in the Category 1 test sequence.

NOTE 2 Some systems are constructed using factory assembled string wiring harnesses, which are cable assemblies that aggregate the output of multiple PV string conductors into a single main conductor. Alternative string test requirements for systems using harnesses are under consideration.

5.3.5 Category 2 test regime

A Category 2 test regime includes additional tests and is intended for larger or more complex systems. All Category 1 tests shall have been undertaken and passed before commencing on the additional Category 2 tests.

In addition to the Category 1 tests, the following tests may be applied:

- a) String I-V curve test.
- b) IR inspection.

As noted in the Category 1 test description, where an I-V curve test is being performed, it provides an acceptable means to derive I_{sc} and V_{oc} .

NOTE 1 In some circumstances just one element or part of the Category 2 test regime may be chosen to be implemented. An example of this is where a client wants the performance evaluation provided by the I-V curve test to be added to the standard Category 1 test sequence.

NOTE 2 In some circumstances Category 2 tests may only be implemented on a sample portion of the system. An example of this is where a client wants I-V curve tests and/or IR inspection on a fixed proportion of the strings.

5.3.6 Additional tests

In addition to the standard suite of tests described in the Category 1 and 2 test sequences, there are also other tests that may be performed in some circumstances. These tests are likely to be implemented either due to a specific request from a client or as a means of detecting faults when other tests or operational abnormalities have suggested a problem that has not been identified by the standard tests.

a) Voltage to ground – resistive ground systems

This test is used to evaluate systems that use a high impedance (resistive) connection to ground. A procedure is described in 8.1.

b) Blocking diode test

Blocking diodes can fail in both open and short circuit states. This test is important for installations where blocking diodes are fitted. A procedure to test blocking diodes is described in 8.2.

c) Wet insulation test

A wet insulation test is primarily used as part of a fault finding exercise: where the results of a standard (nominally dry) insulation test are questionable or where insulation faults due to installation or manufacturing defects are suspected. A wet insulation test procedure is described in 8.3.

d) Shade evaluation

When inspecting a new PV system, a verification of the as-built shade conditions can be a useful record. Like the electrical measurements described in this standard, the shading evaluation provides a baseline for future comparisons as the shading environment changes. A shade record can also be useful to verify that the shading assumptions used for system design are reflected in the as-built system. Shade records are of particular use where a project is subject to a performance guarantee or other similar performance contract. A procedure to record shade is described in 8.4.

6 Test procedures – Category 1

6.1 Continuity of protective earthing and equipotential bonding conductors

Where protective earthing and/or equipotential bonding conductors are fitted on the DC side, such as bonding of the array frame, an electrical continuity test shall be made on all such conductors. The connection to the main earthing terminal should also be verified.

6.2 Polarity test

The polarity of all DC cables shall be verified using suitable test apparatus. Once polarity is confirmed, cables shall be checked to ensure they are correctly identified and correctly connected into system devices such as switching devices or inverters.

NOTE For reasons of safety and for the prevention of damage to connected equipment, it is extremely important to perform the polarity check before other tests and before switches are closed or string overcurrent protective devices inserted. If a check is made on a previously connected system and reverse polarity of one string is found, it is then important to check modules and bypass diodes for any damage caused by this error.

6.3 PV string combiner box test

A single string connected in reverse polarity within a PV string combiner box can sometimes be easy to miss. The consequence of a reversed string, particularly on larger systems with multiple often interconnected combiner boxes, can be significant. The purpose of the combiner box test is to ensure all strings interconnected at the combiner box are connected correctly.

While it is possible to do a polarity test with a digital multimeter, when checking a large number of circuits, the appearance of the "-" symbol can be relatively easy to overlook. As an alternative, the following test sequence indicates a reverse connection through a substantially different voltage reading.

The test procedure is as follows and shall be performed before any string fuses / connectors are inserted for the first time:

- Select a volt meter with voltage range at least twice the maximum system voltage.
- Insert all negative fuses / connectors so strings share a common negative bus.
- Do not insert any positive fuses / connectors.
- Measure the open circuit voltage of the first string, positive to negative, and ensure it is an expected value.
- Leave one lead on the positive pole of the first string tested, and put the other lead on the positive pole of the next string. Because the two strings share a common negative reference, the voltage measured should be near-zero, with an acceptable tolerance range of ± 15 V.
- Continue measurements on subsequent strings, using the first positive circuit as the meter common connection.
- A reverse polarity condition will be very evident if it exists – the measured voltage will be twice the system voltage.

6.4 PV string – Open circuit voltage measurement

The purpose of the open circuit voltage (V_{oc}) measurement within the Category 1 test sequence is to check that modules strings are correctly wired, and specifically that the expected number of modules are connected in series within the string. Missing an interconnection or mistakenly interconnecting the wrong number of modules within a string is a relatively common error, particularly on larger systems, and the open circuit voltage test will rapidly identify such faults.

NOTE Voltages significantly less than the expected value may indicate one or more modules connected with the wrong polarity, one or more shorted bypass diodes or faults due to poor insulation, subsequent damage and/or water accumulation in conduits or junction boxes. High voltage readings are usually the result of wiring errors.

The open circuit voltage of each PV string should be measured using suitable measuring apparatus. This should be done before closing any switches or installing string overcurrent protective devices (where fitted).

The resulting string open circuit voltage reading shall then be assessed to ensure it matches the expected value (typically within 5 %) in one of the following ways:

- a) Compare with the expected value derived from the module datasheet or from a detailed PV model that takes into account the type and number of modules and the module cell temperature.
- b) Measure V_{oc} on a single module, then use this value to calculate the expected value for the string (most suitable where there is stable irradiance conditions).
- c) For systems with multiple identical strings and where there is stable irradiance conditions, voltages between strings can be compared.

- d) For systems with multiple identical strings and where there is non-stable irradiance conditions, voltages between strings can be compared using multiple meters, with one meter on a reference string.

6.5 PV string – Current measurement

6.5.1 General

The purpose of a PV string current measurement test is to ensure the correct operational characteristics of the system and to verify that there are no major faults within the PV array wiring. These tests are not to be taken as a measure of module / array performance.

Two tests methods are possible (short circuit test or operational test) and both will provide information on the correct functioning of the PV string. Where possible, the short circuit test is preferred as it will exclude any influence from the inverters.

NOTE An I-V curve test is also independent of the inverter and provides a good alternative means to perform this test (see 7.2).

6.5.2 PV string – Short circuit test

6.5.2.1 General

The short circuit current of each PV string should be measured using suitable test apparatus. The making / interruption of string short circuit currents is potentially hazardous and a suitable test procedure, such as that described below, should be followed.

Measured values should be compared with the expected value. For systems with multiple identical strings and where there are stable irradiance conditions, measurements of currents in individual strings shall be compared. These values should be the same (typically within 5 % of the average string current, for stable irradiance conditions).

For non stable irradiance conditions, the following methods may be adopted:

- Testing may be delayed.
- Tests may be done using multiple meters, with one meter on a reference string.
- An irradiance meter reading or visual appraisal of the sunlight conditions may be used to consider the validity of the current readings.

NOTE The use of an irradiance meter or visual appraisal of the sunlight conditions is included here solely as a means of determining if the measured current is within the band expected. As noted in the introduction to this section, the short circuit current test is intended to detect faults rather than give any indication of system performance. System performance measurements are deemed to be part of a Category 2 test regime and are best achieved by performing an I-V curve test.

6.5.2.2 Short circuit test procedure

Ensure that all switching devices and disconnecting means are open and that all PV strings are isolated from each other.

A temporary short circuit shall be introduced into the string under test. This can be achieved by one of the following techniques:

- a) use of a test instrument with a short circuit current measurement function (e.g. a specialized PV tester);
- b) a short circuit cable temporarily connected into a load break switching device already present in the string circuit;
- c) use of a “short circuit switch test box” – a load break rated device that can be temporarily introduced into the circuit to create a switched short circuit.

The test instrument shall have a rating greater than the potential short circuit current and open circuit voltage. Where a switching device and/or short circuit conductor is used to form the short circuit, these shall be rated greater than the potential short circuit current and open circuit voltage.

The short circuit current can then be measured using a suitably rated clip-on ammeter, in-line ammeter or test instrument with a short circuit current measurement function.

The short circuit current shall then be interrupted using the load break switching device and the current checked to have gone to zero before any other connections are changed.

NOTE A "short circuit switch box" is an item of test apparatus that can be used for both short circuit tests and also array insulation tests (see 6.7).

6.5.3 PV string – Operational test

With the system switched on and in normal operation mode (inverters maximum power point tracking), the current from each PV string should be measured using a suitable clip-on ammeter placed around the string cable.

Measured values should be compared with the expected value. For systems with multiple identical strings and where there are stable irradiance conditions, measurements of currents in individual strings shall be compared. These values should be the same (typically within 5 % of the average string current for stable irradiance conditions).

For non stable irradiance conditions, the following methods may be adopted:

- Testing may be delayed.
- Tests may be done using multiple meters, with one meter on a reference string.
- An irradiance meter reading may be used to adjust the current readings.
- A specialized PV test meter (with irradiance measurement) may be used.
- An I-V curve test may be performed.

NOTE I-V curve testing is described in 7.2.

6.6 Functional tests

The following functional tests shall be performed:

- a) Switchgear and other control apparatus shall be tested to ensure correct operation and that they are properly mounted and connected.
- b) All inverters forming part of the PV system shall be tested to ensure correct operation. The test procedure should be as defined by the inverter manufacturer.

Functional tests that require the AC supply to be present (e.g. inverter tests) shall only be performed once the AC side of the system has been tested.

6.7 PV array insulation resistance test

6.7.1 General

PV array DC circuits are live during daylight and, unlike a conventional AC circuit, cannot be isolated before performing this test.

Performing this test presents a potential electric shock hazard; therefore, it is important to fully understand the procedure before starting any work. The following basic safety measures should be followed:

- Limit the access to the working area.

- Do not touch and take measures to prevent any other persons touching any metallic surface when performing the insulation test.
- Do not touch and take measures to prevent any other persons from touching the back of the module/laminate or the module/laminate terminals when performing the insulation test.
- Whenever the insulation test device is energized, there is voltage on the testing area. The equipment shall have automatic auto-discharge capability.
- Appropriate personal protective clothing / equipment should be worn for the duration of the test.

Where the results of the test are questionable, or where insulation faults due to installation or manufacturing defects are suspected, a wet array insulation test may be appropriate and may help locate the location of a fault – see 8.3 for a suitable test procedure.

Where SPDs or other equipment are likely to influence the verification test, or be damaged, such equipment shall be temporarily disconnected before carrying out the insulation resistance test.

6.7.2 PV array insulation resistance test – Test method

The test should be repeated, as minimum, for each PV array or sub-array (as applicable). It is also possible to test individual strings if required.

TEST METHOD 1 – Test between array negative and earth followed by a test between array positive and earth.

TEST METHOD 2 – Test between earth and short circuited array positive and negative.

Where the structure/frame is bonded to earth, the earth connection may be to any suitable earth connection or to the array frame (where the array frame is used, ensure a good contact and that there is continuity over the whole metallic frame).

For systems where the array frame is not bonded to earth (e.g. where there is a class II installation) a commissioning engineer may choose to do two tests: i) between array cables and earth and an additional test ii) between array cables and frame.

For arrays that have no accessible conductive parts (e.g. PV roof tiles) the test shall be between array cables and the building earth.

Where test method 2 is adopted, to minimize the risk from electrical arcs, the array positive and negative cables should be short-circuited in a safe manner. Typically this would be achieved by an appropriate short-circuit switch box. Such a device incorporates a load break rated DC switch that can safely make and break the short circuit connection – after array cables have been safely connected into the device.

The test procedure should be designed to ensure the peak voltage does not exceed module, switch, surge arrestor or other system component ratings.

6.7.3 PV array insulation resistance – Test procedure

6.7.3.1 General

Before commencing the test:

- limit access by non-authorized personnel;
- isolate the PV array from the inverter (typically at the array switch disconnect); and
- disconnect any piece of equipment that could have impact on the insulation measurement (i.e. overvoltage protection) in the junction or combiner boxes.

Where a short circuit switch box is being used to test to method 2, the array cables should be securely connected into the short circuit device before the short circuit switch is activated.

The insulation resistance test device shall be connected between earth and the array cable(s) or combiner bus bar – as appropriate to the test method adopted. Test leads should be made secure before carrying out the test.

Follow the insulation resistance test device instructions to ensure the test voltage is according to Table 1 and readings in megaohms.

Ensure the system is de-energized before removing test cables or touching any conductive parts.

6.7.3.2 Insulation resistance – PV arrays up to 10 kWp

For PV arrays of up to 10 kWp, the insulation resistance shall be measured with the test voltage indicated in Table 2. The result is satisfactory if each circuit has an insulation resistance not less than the appropriate value given in Table 2.

Table 2 – Minimum values of insulation resistance – PV arrays up to 10 kWp

System voltage ($V_{oc} \text{ (stc)} \times 1,25$) V	Test voltage V	Minimum insulation resistance MΩ
<120	250	0,5
120 to 500	500	1
>500	1 000	1

6.7.3.3 Insulation resistance – PV arrays above 10 kWp

For PV arrays of over 10 kWp, one of the following two test methods shall be followed.

Method A

Perform the insulation resistance test on:

- individual strings; or
- combined strings, where the total combined capacity is no more than 10 kWp.

The insulation resistance shall be measured with the test voltage indicated in Table 2. The result is satisfactory where the insulation resistance is not less than the appropriate value given in Table 2.

Method B

Method B is an alternative that allows for testing of an entire array (or sub-array) even if it is larger than 10 kWp. Arrays larger than 10 kWp may pass the requirements of Table 2; hence Method B provides a shortcut (testing the entire array at the outset) – only if it fails this test should the test be performed on sub-sections as per Method A.

The insulation resistance shall be measured with the test voltage indicated in Table 2. The result is satisfactory where the insulation resistance is not less than the appropriate value given in Table 2.

If the measurement falls below the appropriate value given in Table 2, the system should be re-tested using fewer strings in the test circuit.

7 Test procedures – Category 2

7.1 General

Category 2 tests can be implemented on all parts of a system or only upon sample portions.

NOTE It is relatively common, particularly for large systems, that some of the Category 2 tests are performed on a selected sample of the system (a fixed percentage of the strings / modules). Such a selective approach and the percentage of the system to be tested will be agreed with the client prior to commissioning.

7.2 String I-V curve measurement

7.2.1 General

A string I-V curve test can provide the following information:

- Measurements of string open circuit voltage (V_{oc}) and short circuit current (I_{sc}).
- Measurements of max power voltage (V_{mpp}), current (I_{mpp}), and max power (P_{max}).
- Measurement of array performance.
- Measurement of module / string fill factor.
- Identification of module / array defects or shading issues.

Before undertaking an I-V curve test, the I-V curve test device shall be checked to ensure it is suitably rated for the voltage and current of the circuit under test.

7.2.2 I-V curve measurement of V_{oc} and I_{sc}

An I-V curve test is an acceptable alternative method to derive the string open circuit voltage (V_{oc}) and short circuit current (I_{sc}). Where an I-V curve test is performed, separate V_{oc} and I_{sc} tests are not required – provided the I-V curve test is performed at the appropriate stage in the Category 1 test sequence.

The string under test should be isolated and connected to the I-V curve test device. If the purpose of the I-V curve test is solely to derive values for V_{oc} and I_{sc} , then there is no requirement to measure irradiance (or cell temperature).

7.2.3 I-V curve measurement – Array performance

Given suitable irradiance conditions, an I-V curve test provides a means to measure that the performance of a PV array is meeting the rated (nameplate) performance.

PV string and array performance measurements shall be performed at stable irradiance conditions of at least 400 W/m² as measured in the plane of the array.

NOTE 1 Poor results may be expected where measurements are taken in low irradiance or where the angle of incidence is too oblique.

NOTE 2 The maximum power current and voltage of a PV string are directly affected by irradiance and temperature, and are indirectly affected by any changes in the shape of the I-V curve. In general, I-V curve shape varies slightly with irradiance, and below a critical level of irradiance the curve shape changes dramatically. The details of the variation depend on the PV technology and the extent to which module performance has been degraded over time. Changes in the shape of the curve can cause errors in evaluating array performance, regardless of the method used to characterize string performance (I-V curve tracing or separate current and voltage measurements).

The procedure for undertaking the I-V curve test is as follows: