PV GAP RECOMMENDED SPECIFICATION

PVRS 11A

2005-03

Portable solar photovoltaic (PV) lanterns– Design qualification and type approval

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PORTABLE SOLAR PHOTOVOLTAIC (PV) LANTERNS DESIGN QUALIFICATION AND TYPE APPROVAL

1 Scope

The specifications, test methods and procedures for indoor tests included in this document cover portable solar photovoltaic lanterns, which are lighting systems consisting of a lamp, a lead-acid battery and electronics, all placed in a suitable housing made of durable material such as metal or plastic and an integrated or separate PV module. The battery is charged by electricity generated through the solar photovoltaic module. The lantern is basically a portable lighting device suitable for indoor lighting. For the purpose of this standard the service environment of the lantern (without the PV module) can be described as being fully covered by a building or enclosure to protect it from direct rain, sun, wind-blown dust, fungus, and radiation to the cold night sky, and the like, but the building or enclosure is not conditioned in terms of temperature, humidity or air filtration.

A lighting device (such as typical flashlights), which provides only unidirectional lighting, will not be classified as a solar lantern in the present context.

The focus of the test methods and procedures in this document is on solar lantern performance and durability evaluation and therefore includes the lantern components.

The results of this test are applicable to the exact components and the entire lantern configuration that are tested, as specified in the Blank Detail Specification (BDS) sheet or Conformity Assessment Report (CAR).

The chosen testing condition is intended to represent the majority of climatic zones for which these solar lanterns are designed.

Note 1:The test procedure is composed to ensure a lifetime expectancy under conditions of normal use and in moderate climatic conditions of five years and beyond, without major need for maintenance such as change/replacement of modules, charge controller, batteries, lamps or switches.

Note 2: The test logic is similar to that defined in IEC 62124 for Solar Home Systems (SHS). Testing laboratories qualified to test SHS against IEC 62124 have therefore both test equipment and expertise in performing the tests.

Note 3: For solar lanterns, some of the regular functions of the modern charge controller in other standalone PV systems may not be available because of the more simple nature of the solar lantern. On the other hand, electronic ballast of the lamp may already be included in the electronic circuit.

Note 4: The scope of this standard is limited to lead-acid batteries and to fluorescent lamps, since the majority of available lanterns incorporate these technologies. Newer technologies such as NiMH batteries and Light Emitting Diodes (LED) lamps are under consideration for future editions.

Note 5: Annex D contains design recommendations, which are not normative. However, experience has shown that many of these design aspects are positively correlated to the solar lantern's performance.

2 Purpose

The purpose of this specification is to verify design, performance and durability of portable solar PV lanterns. While individual components must be qualified to environmental, performance and safety specifications, the assembled lantern needs further qualification, to ensure that the components operate properly together as specified by the lantern manufacturer. The performance test consists of a check of the functionality, the autonomy and the ability to recover after periods of low state-of-charge of the battery, and hence gives reasonable assurance that the solar lantern will not fail prematurely.

3 Normative references

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this International Specification. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this International Specification are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and International Standards Organization (ISO) maintain registers of currently valid International Standards. PV GAP Recommended Specifications can be obtained from PV GAP.

IEC 60068-2-6: 1995, *Environmental testing – Part 2 : Tests – Test Fc: Vibration (sinusoidal)*

IEC 60529: 1989, *Degrees of protection provided by enclosures (IP Code)*

IEC 60904-1: 1987, *Photovoltaic devices. Part 1: Measurement of photovoltaic current-voltage characteristics*

IEC 60904-2: 1989, *Photovoltaic devices. Part 2: Requirements for reference solar cells*

IEC 60904-5 :1993, *Photovoltaic devices. Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method*

IEC 60904-9: 1995, *Photovoltaic devices - Part 9: Solar simulator performance requirements*

IEC 61215: 1993, *Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval.*

IEC 61646: 1996, *Thin-film silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval.*

IEC 61724:1998, *Photovoltaic system performance monitoring. Guidelines for measurement, data exchange and analysis.*

IEC 61725: 1997, *Analytical expression for daily solar profiles*

IEC 61730-1:2004, *Photovoltaic (PV) module safety qualification – Part 1: Requirements for construction*

IEC 61730-2: 2004, *Photovoltaic (PV) module safety qualification – Part 2: Requirements for testing*

IEC 61853*, Performance testing and energy rating of terrestrial photovoltaic (PV) modules (under consideration)*

IEC 62093, *Balance-of-system components for photovoltaic systems – Design Qualification (under consideration)*

IEC 62124: 2004, *Photovoltaic (PV) stand-alone systems - Design Verification*

ISO/IEC 17025: 1999, *General requirements for the competence of testing laboratories and calibration laboratories*

PVRS 2: 2003 *Crystalline silicon terrestrial photovoltaic (PV) modules – Blank detail specification*

PVRS 3: 2002 *Thin-film terrestrial photovoltaic (PV) modules – Blank detail specification*

PVRS 5A: 2003 *Lead-acid batteries for solar photovoltaic energy systems – General requirements and methods of test for modified automotive batteries*

PVRS 6A: 2000 *Charge controllers for photovoltaic (PV) stand-alone systems with a nominal system voltage below 50V*

PVRS 7: 2005*, DC supplied systems. Blank detail specification*

PVRS 7A: 2003 *DC supplied lighting systems with fluorescent lamps for photovoltaic (PV) stand-alone systems*, Annex – Specification and testing procedure to PVRS 7

4 Abbreviations

AC: Alternating Current

Ah: Ampere-hours

CAR: Conformity Assessment Report

CFL: Compact Fluorescent Lamp

DC: Direct Current

DRT: Daily Run Time (of the solar lantern)

FS: Full Screen

HVD: High Voltage Disconnect (of the charge controller)

LVD: Low Voltage Disconnect (of the charge controller)

MPP: Maximum Power Point

NOCT: Nominal Operating Cell Temperature

PV: Photovoltaic(s)

STC: Standard Testing Conditions (Reference testing value of cell temperature (25°C), in-plane irradiance (1000W/m²), air mass solar reference spectrum (AM = 1.5) for PV module or PV cell electrical performance testing)

TMP: Typical Mean Daily

UBC: Usable Battery Capacity

VI: Visual Inspection

5 Testing methods

The tests in this specification are conducted to gauge the performance under conditions of irradiance and temperature that cover a large part of the world where these solar lanterns are being used. However these tests can be adapted to meet other specific climatic conditions, if those are significantly different from the testing conditions in this specification.

This solar lantern qualification procedure is based on two series of tests:

- To test the solar lantern components such as the PV module, the lead-acid battery, the light bulbs, the manual on-off switch and the module connecting device, and
- To test the solar lantern as the entire unit.

The first series of tests are component tests, to determine whether the module, the lead-acid battery and the lamp are appropriate for use in a solar lantern application. The second test procedure then is a type approval, to verify whether or not the component configuration in the solar lantern is well optimized to provide the lighting services for which the solar lantern is specified.

These two tests are independent and essential steps for evaluating the quality of solar lanterns. Components previously tested according to the procedure in this specification and already certified do not need retesting.

The battery test (PVRS 5) and the fluorescent lamps test (PVRS 7A) have been developed under the leadership of PV GAP, and are available through PV GAP.

Usually, solar lanterns powered by photovoltaic modules having a maximum STC power output less than 10 Watts under standard testing conditions, can be subjected to a reduced test sequence, which is based on either IEC 61215 or IEC 61646, as described in clause 11 of this specification. However, if these modules are from a family of modules, that has either an IEC 61215 or 61646 certificate, this small module is considered to be certified for the solar lantern application without any further tests.

5.1 Sampling

Three complete solar lanterns for qualification testing (plus spares as specified by the supplier) shall be taken at random from a production batch or batches. The systems shall have been manufactured from specified materials and components in accordance with the relevant drawings and process sheets and have been subjected to the manufacturer's normal inspection, quality control and production acceptance procedures. The solar lanterns shall be complete in every detail and shall be accompanied by the manufacturer's handling, mounting and connecting instructions, including safety instructions.

A copy of the relevant test certificate for the PV-module, battery (or batteries) and lamp(s) shall be included, if present. Otherwise these tests must be performed independently.

When the solar lanterns to be tested are prototypes of a new design and not from production, this fact shall be noted in the test report (clause 20). In this case, certificates will not be eligible for type approval certification.

If the lamps are sealed or components are not accessible (potted) and the configuration is based on an inverter/electronic ballast between battery and fluorescent lamps, the solar lantern has to be provided in a nonsealed/nonpotted version, with the components accessible for measuring current/voltage characteristics to perform the tests. If DC CFL units with integrated inverter are used, this is not necessary, even when the lantern is potted. The lamp current will then be measured with an interface between the lamp socket and the lamp.

If the solar lantern is designed for different lamps with different run times for each lamp, the configuration with the largest power consumption shall by default be tested. The manufacturer may, however, deviate from this procedure and select the configuration for which he wants to get the certification.

5.2 Testing sequence

In carrying out the tests, the test operator shall strictly follow the manufacturer’s handling, mounting and connection instructions.

First two of each of the components shall be tested. If the components bear a relevant type approval certificate such as the PV GAP “PV Quality Mark” no testing is necessary. If the components do not bear a type approval certificate, they shall be subjected to the test sequences in this specification, carried out in the order laid down. If both components fail any test, the design shall be deemed not to have met the qualification requirements. If one of the two components fails any test, the third component shall be subjected to the whole of the relevant test sequence from the beginning. If this component also fails, the design shall be deemed not to have met the qualification requirements.

Once all the components have passed the component tests, the solar lanterns shall be subjected to the shipping vibration test and the lantern performance test. The procedures of the lantern performance test are subdivided into three different tests: the functional test, the autonomy test and the recovery test.

The lantern shall be subjected to the test sequences in this specification, carried out in the order described.

If both lantern samples fail any test, the design shall be deemed not to have met the qualification requirements. If one of the two lantern samples fails any test, a third lantern shall be subjected to the entire relevant test sequence from the beginning. If this lantern also fails, the design shall be deemed not to have met the qualification requirements.

Figure 1 represents the qualification process.

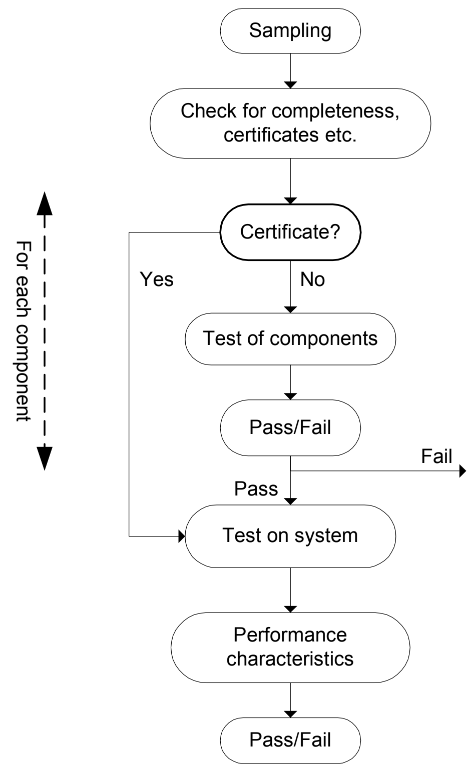


Figure 1 Flow diagram representing the qualification process

5.3 Testing levels and criteria

The Table 1 contains an overview of the tests, testing conditions and criteria.

Table 1 Test Overview

Test	**Conditions**	**Criteria**
PV module	The PV module as specified by the manufacturer and included in the set shall bear a type approval certificate from an internationally recognized PV quality system (constitutes acceptability).	IEC 61215 or PVRS 2, or IEC 61646 or PVRS 3
PV module	The PV module does not have a certificate but the criteria to the right are met (constitutes acceptability).	The manufacturer manufactures certified modules of a similar type and the module power is lower than 10 W.
PV module	The PV module does not have a certificate, the module power is lower than 10 W and the manufacturer does not manufacture certified modules of a similar type.	A standard module test is passed, limited to • Outdoor exposure test • Damp-heat test • Robustness of terminations test.

Test	**Conditions**	**Criteria**
Battery	Certificate required (constitutes acceptability)	PVRS 5A
Lamp	Certificate required (constitutes acceptability)	PVRS 7A
Switching and PV module connector durability test	1,000 cycles	• Functionality and safety evaluated • Resistance of connector <20 mΩ
Open circuit test of the ballast	Input voltage 1.2 times the nominal battery voltage, repeat twice.	The lantern shall function.
Open circuit test of the charge controller	Remove the battery. Apply 1,25 times open-circuit voltage to the PV module input terminals of the charge controller.	The charge controller must withstand the condition without any damage.
Reverse polarity of the PV module	Apply a reverse polarity voltage equal to 1.5 times the nominal open-circuit voltage of the PV module to the PV module input terminals of the charge controller.	The charge controller must withstand the condition without any damage.
Reverse polarity of the battery	Apply a reverse polarity voltage equal to 1.2 times the nominal battery voltage to the battery input terminals of the charge controller.	The charge controller must withstand the condition without any damage.
Fuses	The battery shall be protected against short-circuit by (a) fuse or fuses, as close as possible to the battery terminals.	Overcurrent devices shall be rated for at least 156% of the short circuit current (at STC) and shall have a voltage rating of at least 125% Voc.
Shipping vibration test	10 Hz to 11,8 Hz; 11,9 Hz to 150 Hz • Amplitude: 3,5 mm, • Acceleration: 2 g • Cycling: 1 octave/min, • Duration on each axis: 2 h; overall: 6 h.	The lantern shall function.
System performance tests	• Functional test • Autonomy test • Recovery test	1. The lamp must function at all stages of the test unless the charge controller has disconnected the lamp due to a low battery state of charge. 2. The battery capacity shall not decrease over the testing period more than 10%, expressed by $(C_0-C_2)/C_0 < 10\%$; C_o is the initial battery capacity and C_2 is the final battery capacity.

Test	Conditions	Criteria
		3. The ‘recovery test’ should exhibit an upward trend in the system voltage. During the recovery test, the total net Ah into the battery should be >=50% of C_1 where C_1 is the battery capacity after recovery test. 4. After capacity test C_1, the load shall begin operating again on or before the third ‘recovery test’ cycle. 5. The System Balance Point (see System Characterization Plot) shall match or stay below the defined minimum irradiation class. 6. The measured days of autonomy shall match or exceed the defined minimum days of autonomy as indicated by the manufacturer. 7. The lamp shall operate undamaged according to the manufacturer’s specification at the maximum battery voltage occurring during periods of high irradiance and at high state of charge. 8. No sample shall exhibit any abnormal open-circuit or short-circuit conditions during the tests.

6 Marking

The manufacturer shall provide the solar lantern and the PV module (if not integrated) with the following clear and indelible markings:

- Name, monogram or symbol of the manufacturer/supplier
- Type or model number
- Nominal module and battery voltage
- Serial or batch number
- Polarity of terminals or leads
- Precautionary warning concerning special requirements for storage or handling

The date and place of manufacture shall be marked on the component or be traceable from the serial number.

All components must be provided with relevant documents concerning their rating, certificates and specifications in the language of the user and/or technician. Instead of a written user’s manual, illustrations may be used where appropriate.

Labeling on equipment shall be in accordance with good ergonomic principles so that warning notices, controls, indications, testing facilities, fuses and the like, are sensibly placed and logically grouped to facilitate correct and unambiguous identification.

7 Pass criteria

A solar lantern design shall be judged to have passed the qualification test if each test sample meets all the following criteria:

7.1 Solar lantern completeness

The lantern shall be complete and contain the following elements:

- All the necessary hardware
- Specification by the manufacturer of Daily Run Time (DRT) under testing conditions. For the purpose of this test, DRT is based on the irradiation class III, as shown in Annex A;
- Specification by the manufacturer concerning the design load (Watt-hour), the irradiation level for which this design load can be energized by the solar lantern, the autonomy and the classification under design conditions (see Annex A). These specifications enable the test lab to verify the manufacturer’s calculations
- Specification by the manufacturer concerning the days of autonomy under testing conditions
- Certificates
- Manual, including list of spare parts and tools, as described in clause 8.

7.2 The PV Module

The PV module as specified by the manufacturer and included in the set shall bear a type approval certificate from an internationally recognized PV quality system.

The PV module shall be certified according to IEC 61215 or PVRS 2 in case of crystalline silicon PV modules and according to IEC 61646 or PVRS 3 in case of thin film PV modules.

In case the module does not bear a certificate, the following three requirements shall be met:

(i) The module manufacturer already has larger module(s) certified against IEC 61215 or PVRS 2 in case of crystalline silicon PV modules and according to IEC 61646 or PVRS 3 in case of thin-film PV modules.

(ii) The peak power rating of the solar lantern module is less than 10 Watts.

(iii) The module for the solar lantern applies the same materials (including but not limited to solar cells, interconnecting material, encapsulants, and junction box connections) and is made in the same factory using the same manufacturing installation as for the module(s) for which the manufacturer has received certification.

In case the module does not bear a certificate and one or more of the above three criteria do not apply, the module shall be qualified for solar lantern application following the tests described in clause 11.

> Note: The reason for simplifying some of the requirements for modules of solar lantern is based on the following: Solar lanterns are designed for a minimal lifetime of five years, and normally their price reflects the lower life expectancy compared to larger systems. In view of the different lifetime expectation and the smaller sizes, reducing some of the severe tests of IEC 61215 or IEC 61646 is justified. The retesting of the complete module is unnecessary if the module manufacturer already has in the same module family

larger modules certified.

7.3 The battery

The battery as specified by the manufacturer and included in the set shall bear a type approval certificate from an internationally recognized PV quality system.

The battery shall be certified according to PVRS 5.

7.4 The lamp(s)

The lamp(s) as specified by the manufacturer and included in the set shall bear a type approval certificate from an internationally recognized PV quality system.

The lamps shall be certified according to PVRS 7.

7.5 Protection against open-circuit, short-circuit and reverse polarity

The inverter shall be protected against damage from voltage under open-circuit conditions (for example, when the lamp is removed or has failed).

The charge controller shall be protected against damage from voltage under open-circuit conditions when the battery is removed or has failed and from short-circuit conditions when the PV module terminals are short-circuited.

The charge controller shall be protected against damage from reverse polarity conditions of the battery and the PV module.

7.6 Fuses and circuit breakers

The battery shall be protected against short-circuit by a fuse or fuses, as close as possible to the battery terminals.

Soldered fuses on the printed circuit board are also allowed. Where fuses of different capacity are installed, they shall have clear color coding or labeling or be of different physical size.

Fuses shall meet the following conditions:

- Be sized per the conductor size and per the component they are protecting as specified by the manufacturer
- Be marked with rated current, voltage and use (AC or DC)
- Be rated for DC service in DC applications
- Have appropriate voltage ratings for the circuit they are protecting.

Overcurrent devices protecting PV source and output circuits and carrying currents from the PV modules shall be rated for at least 156% of the short circuit current (at Standard Test Conditions) and shall have a voltage rating of at least 125% Voc.

7.7 Switch and module connectors

Switches suitable for DC use are to be provided on the lantern. The switch shall be able to withstand a minimum of 1000 cycles under load.

The PV module connector shall be able to withstand a minimum of 1000 connections cycles.

A test sequence is provided in clause 12.

7.8 System performance tests

The system shall pass the system performance tests described in clause 15

The following pass-fail-criteria apply:

1. The lamp must function at all stages of the test unless the charge controller has disconnected the lamp due to a low battery state of charge (LVD).
2. The battery capacity shall not decrease over the testing period more than 10 percent, expressed by $(C_0-C_2)/C_0 < 10$ percent; C_o is the initial battery capacity and C_2 is the final battery capacity.
3. Recovery: the 'recovery test' should exhibit an upward trend in the system voltage. During the recovery test, the total net Ah into the battery should be >=50 percent of C_1 where, C_1 is the battery capacity after recovery test.
4. After capacity test C_1, the load shall begin operating again on or before the third 'recovery test' cycle.
5. The System Balance Point (see System Characterization Plot) shall match or not exceed the defined minimum irradiation class.
6. The measured days of autonomy shall match or exceed the defined minimum days of autonomy as indicated by the manufacturer.
7. The lamp shall operate undamaged according to the manufacturer's specification at the maximum battery voltage occurring during periods of high irradiance and at high state of charge.
8. No sample shall exhibit any abnormal open-circuit or short-circuit conditions during the tests.

7.9 Visual evidence of a major defect

There shall be no visual evidence of a major defect, as defined in clause 9, both before and after the components tests as well as the system performance test as described in clause 14.

8 Manual

The manual shall be written in English and the user's language and shall include the following:

- A complete list of all system components and spare parts, with associated manufacturers literature, specifications and warranties.
- A complete set of electrical schematic, mechanical composition, functional block diagram and layout.
- Battery safety requirements including maintenance/replacement procedures.
- Lamp maintenance/replacement procedures.
- Installation instructions that ensure proper placement of the PV module and lamp assembly. The lamp must be installed in a protected environment to be consistent with the scope of this specification.

- Procedures for proper system operation, including load conservation during periods of inclement weather, and/or a low voltage disconnect event. A checklist that contains what to do in case of a system failure shall be included. The procedures for checking that the PV module is not shaded and how to prevent shading must be explained.
- Maintenance items.
- A troubleshooting guide referencing all the system components. This must include repairs and diagnostic procedures that can be done by the supplier.

Lantern performance must be specified in the following terms:

- Rated average energy supply (Wh/day)
- Autonomy (number of days without sunshine the lantern can service the load)
- Hours of use of lamp
- Test conditions.

9 Major defects

For the purpose of design qualification, the following are considered to be major defects:

- Failure of any system component, including the on/off switch
- Broken, cracked, bent, misaligned or torn external surface of any component (PV module, battery, charge controller, or other balance of system (BOS) component)
- Browning of any printed circuit board
- Loss of mechanical integrity, to the extent that the installation and/or operation of the system would be impaired
- Deterioration of wiring insulation
- Electrolyte leakage from the batteries
- Signs of overheating or corrosion.

10 Load specification

Many solar lanterns have multiple lighting modes, which may be activated by incorporating two lamps or via electronic controls.

For the purpose of this test the lamp shall be operated at maximum power.

The manufacturer shall specify the daily number of hours the system can service the load under the test conditions described in this specification (DRT). This number shall be derived using the irradiation class III, specified in Annex A.

For the purpose of the test and while the PV modules are connected, the load is never operated during daylight or at times when the solar irradiance is above 50 W/m².

11 Solar PV modules test

The purpose of this test sequence is to determine the electrical characteristics of the module and to show, as far as possible within reasonable cost and time constraints that the module is capable of matching the expected lifetime that a solar lantern is expected to have.

The test is a simplified version of the IEC module test according to IEC 61215 in the case of crystalline silicon PV modules or according to IEC 61646 in the case of thin-film PV modules.

For the purpose of this standard the testing procedure under clause 10 of IEC 61215 or IEC 61646 is limited to the following three tests:

- Outdoor exposure test
- Damp-heat test
- Robustness of terminations test.

12 Switching and solar module connector durability test

12.1 Purpose

The purpose of this test is to ensure that the switch and the module connector are able to withstand normal use and do not fail prematurely.

12.2 Procedure

Subject the switch to an initial electrical resistance measurement test. In case the switch has a resistance of more than 20mΩ, the switch has failed the test.

Make sure the lantern is fully charged and ready for use.

1) Switch on the light; in case there is more than one switch, use all the switches.
2) Switch off the light.
3) Connect the module to the lantern housing.
4) Flex the module cable at the connector and disconnect the module from the lantern.

Repeat the procedure 1000 times.

Measure the electrical resistance over the module connection.

12.3 Requirements

None of the components must show signs of wear that endanger the functionality or cause potential safety hazards.

The switch must function and the module connector must not exhibit an electrical resistance value more than 20 mΩ.

13 Protection against open-circuit, short-circuit and reverse polarity tests

13.1 Open-circuit test of the ballast

13.1.1 Procedure

A. Connect the lamp with the electronic ballast to a regulated power supply. Adjust the input voltage to 1.2 times the nominal battery voltage. Remove the lamp, turn the switch on and off twice, leave the set-up for 1 hour and put the lamp back. Wait at least 1 minute. Repeat this test twice without waiting for 1 hour.

Requirement: The lantern shall function.

B. Connect the electronic ballast to the regulated power supply. Do not connect the lamp. Adjust the input voltage to 1.2 times the nominal battery voltage, wait at least 1 minute and measure the input current.

Requirement: The ballast shall function properly. This is normally the case when the input current is not more than 10 mA.

Note: Not all lanterns incorporate electronically controlled ballasts.

13.2 Open-circuit test of the charge controller

13.2.1 Procedure

Apply a voltage equal to 1.25 times the open-circuit voltage of the PV module to the PV module input terminals of the charge controller using a regulated power supply. Remove the battery. Wait at least 1 minute.

Requirement: The charge controller must withstand the condition without any damage.

Requirement: When the battery is removed, the PV voltage must not “snap through” to the load terminals! Otherwise the load can be destroyed. This means that the charge controller must cut down the PV-voltage in case of a removed battery.

13.3 Reverse polarity test of the charge controller

13.3.1 Procedure for reverse polarity of the PV module

Apply a voltage equal to 1.5 times the nominal open-circuit voltage of the PV module to the PV module input terminals of the charge controller using a regulated power supply connected with reverse polarity. Wait at least 1 minute.

Requirement: The charge controller must withstand the condition without any damage.

13.3.2 Procedure for reverse polarity of the battery

Apply a voltage equal to 1.2 times the nominal battery voltage to the battery input terminals of the charge controller using a regulated power supply connected with reverse polarity. Wait at least 1 minute. Observe any irregularities (excessive heat, smoke, fire, damaged components, etc) with the charge controller.

Requirement: The charge controller must withstand the condition without any damage.

Note: Battery protection fuses may blow, which is a normal outcome and should not be interpreted as a failure of this test.

14 Shipping vibration test

14.1 Purpose

The purpose of this test is to identify mechanical weak points and/or to ascertain any deterioration of the specified performance. According to IEC 60068-2-6, it must be conducted on structural elements or devices that are exposed to harmonic vibrations during shipment, such as occur on ships, in aircraft and land vehicles.

14.2 Requirements

Frequency range:	10 Hz to 11,8 Hz; 11,9 Hz to 150 Hz
Constant amplitude:	3,5 mm
Constant acceleration:	2 g
Cycling:	1 octave/min
Duration on each axis:	2 h
Total test duration:	6 h

14.3 Apparatus

See IEC 60068-2-6.

14.4 Procedure

See IEC 60068-2-6.

The specimens are neither packaged nor energized during the test.

15 Solar lantern performance tests

15.1 Instrumentation and equipment

Annex B contains a description of the instrumentation and equipment for the solar lantern tests.

15.2 Test documentation

In addition to recording all the relevant system data, the test operator shall keep relevant test data, calculations, and appropriate comments. An electronic copy of the system data shall be kept for future reference.

15.3 Installation

Operate the solar lantern according to the manufacturer’s instructions.

For indoor testing, a '"class C", as defined in IEC 60904-9, or better solar simulator shall be used.

15.3.1 Solar lantern preconditioning

Follow the manufacturer's instructions for adding electrolyte (in case of flooded batteries) and preconditioning the battery for system operation.

If battery preconditioning is not called for in the solar lantern documentation, the battery shall be subjected to:

- At least five cycles from High Voltage Disconnect (HVD) to Low Voltage Disconnect (LVD) in an outdoor test, or
- At least five cycles at C_{10} for an indoor test.

> Note: Certain advanced charge controllers need a few days/cycles to find the optimum settings matching the system design. The manufacturer shall state this and the performance test shall be preceded by the prescribed number of cycles.

PV modules exhibiting light-induced degradation (for example. amorphous silicon) shall be subjected to initial light soaking according to IEC 61646.

15.3.2 Verify load operation

The lamp is an integral part of the solar lantern and the size of the lamp is an important design parameter. Lanterns may contain more than one lamp or can be varied in brightness. For the purpose of this test, always use the maximum light output as specified by the manufacturer.

Verify that the lamp starts and operates properly.

In systems with multiple lamps, verify that each individual lamp can start and run while all other lamps are operating.

For this test, it is only necessary to operate the lamp(s) long enough to determine whether they function correctly.

Turn off all lamps after verifying they operate properly.

15.3.3 Data acquisition system installation

Install the plane of the module irradiance sensor (reference device). The irradiance sensor shall be as close as possible to the PV module without shading the module and shall be mounted in the same plane and within +/- 5° of the module tilt angle.

Program the data acquisition system to monitor the measurement parameters and store as 5-minute averages.

Install the temperature sensors:

- The ambient temperature sensor must be mounted in an aspirated or double-shaded shield.
- The temperature sensor on the back of the module must be mounted in the middle of a solar cell within the center of a module, utilizing thermal paste and covering the sensor with insulation material and foil.

- The battery temperature sensor must be mounted as close as possible to the temperature compensation sensor. If temperature compensation is internal to the charge controller, a temperature sensor in addition to the battery temperature sensor shall be mounted to sense the controller temperature.

Install voltage sensors for the PV module and loads.

Install the voltage sensor for the battery at the battery terminals.

Maximum and minimum values of the signals specified in Annex Table B-1 shall also be collected and stored.

Install current sensors for the PV module, battery and lamp.

Calculate module and load DC Power. DC power may be computed by multiplying average DC voltage and average DC current.

Install a sensor to detect proper load operation, for example a light sensor in front of a lamp.

> Note: In case of a fluorescent lamp, it would not be adequate to only look at the current load as an indicator of load operation because the lamp could malfunction yet the ballast may continue to draw current.

Note the load operation method.

Modify a copy of the schematic to show the data acquisition system sensor locations.

This modified schematic shall be included in the report of clause 20.

15.3.4 Lantern photographs

Photograph the lantern after the lantern has been instrumented. Include the photos with the documentation.

15.4 Visual inspection

The lantern and its components must be checked for damage and workmanship (for example, suitability of structural elements)

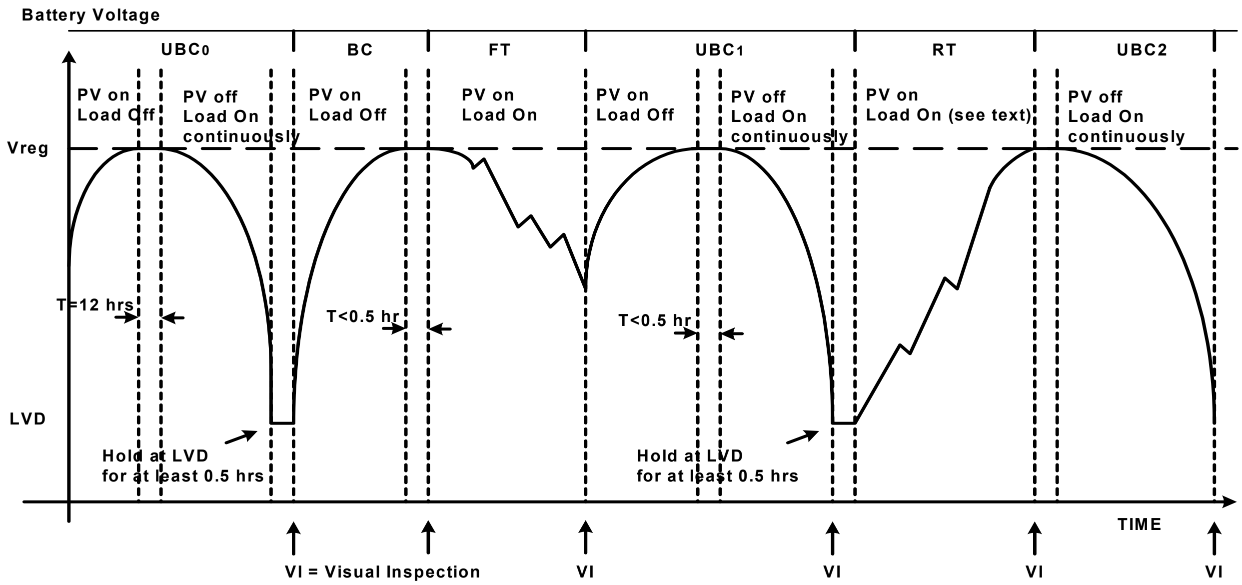
After each test, flex all conductors along their entire length, noting any discoloration or brittleness of the insulation. Undersized conductors and poor connections will tend to overheat, leading to brittle and discolored insulation.

Any peculiarities observed must be carefully documented in the report (clause 20) and if necessary by means of photography.

Verify that all parts listed on the parts list are present. Note any missing system parts that should have been included. If essential parts, that is, parts without which the system cannot go through the testing procedure, are missing, the system shall be deemed to have failed the test and shall be sent back to the manufacturer.

15.5 Test sequences

The Figure 2 indicates the steps of the system performance test, as described in more detail in clause 16:



Sample Test Profile for the solar lantern performance test

Figure 2 Steps in the System Performance Test

Various test sequences are applied during the test to verify performance for low discharge, battery recovery, functionality operation and ability to reach HVD under normal operation in sunny weather, even after having been completely discharged. These tests are outlined below.

UBC_0 = Initial Usable Battery Capacity Test: Initial capacity test – After installing the system, charge and discharge the battery, and measure the usable battery capacity (UBC).

Vreg = voltage level at which the controller determines a “full battery level”

BC = Battery Charging: Recharge the battery before running the Functional Test.

FT = Functional Test: Run the Functional Test to verify that the system and load operate properly.

UBC_1 = First Usable Battery Capacity Test: Capacity test and autonomy test – Charge and discharge the battery. Measure the usable battery capacity. Determine the system autonomy.

RT = Recovery Test: Determine the ability of the PV System to recharge the discharged battery.

UBC_2 = Second Usable Battery Capacity: Final capacity test – Charge and discharge the battery. Measure the usable battery capacity.

15.6 System characterization graph

Plot the values found in the tests and construct the system characterization graph as described in clause 17.

Determine the System Balance Point.

16 Lantern Testing Sequence

16.1 Lantern testing conditions

The temperature of the batteries shall be kept at 27 °C ± 3 °C.

The general ambient temperature during testing shall be within 27 °C ± 3 °C

The test is valid both for using a solar simulator or a solar module simulator. Both shall have the ability to simulate the Reference Solar Day using the Daily Irradiance Profiles as described in this specification.

The solar simulator shall be Class C or better. However, for days with a high solar irradiation a three-step profile is allowed. For days with a low solar irradiation, a constant value of the irradiance is allowed. This specification may be amended to allow the use of non-solar simulators upon the publication of IEC 61853: Performance testing and energy rating of terrestrial photovoltaic (PV) modules (under consideration).

The requirements for the solar module simulator are described in annex C.

16.2 Initial capacity test

Make sure the system has been properly preconditioned in accordance with clause 15.3.1.

With PV on and load off allow the lantern to charge the battery by imposing at least 700 W/m². Once the lantern reaches a state of regulation, keep the lantern at this state for 12 hours. The battery will then be regarded as charged.

With PV off and load on continuously, allow the lantern to fully discharge the battery. The battery is fully discharged when it reaches LVD. Allow the battery to remain at LVD for 5 hours. Record the number of Ah discharged from the battery. This is the Initial Usable Battery Capacity (UBC_0).

Perform a visual inspection as described in the section in accordance with clause 15.4.

16.3 Battery charge cycle

Switch off the light. Set the simulator at 700 W/m² ± 50 W/m². With PV on and load off let the module recharge the battery until it has reached regulation (HVD). Allow the lantern to stay there for a maximum of 0.5 hours. Record the number of Ah recharged into the battery.

16.4 Lantern functional test

This test verifies that the lantern can service the load as intended.

With PV on and light on as specified by the manufacturer in accordance with clause 10, allow the lantern to operate “normally” for 10 days.

The Figure 3 gives an overview of the recommended irradiance profiles to be used in the test.

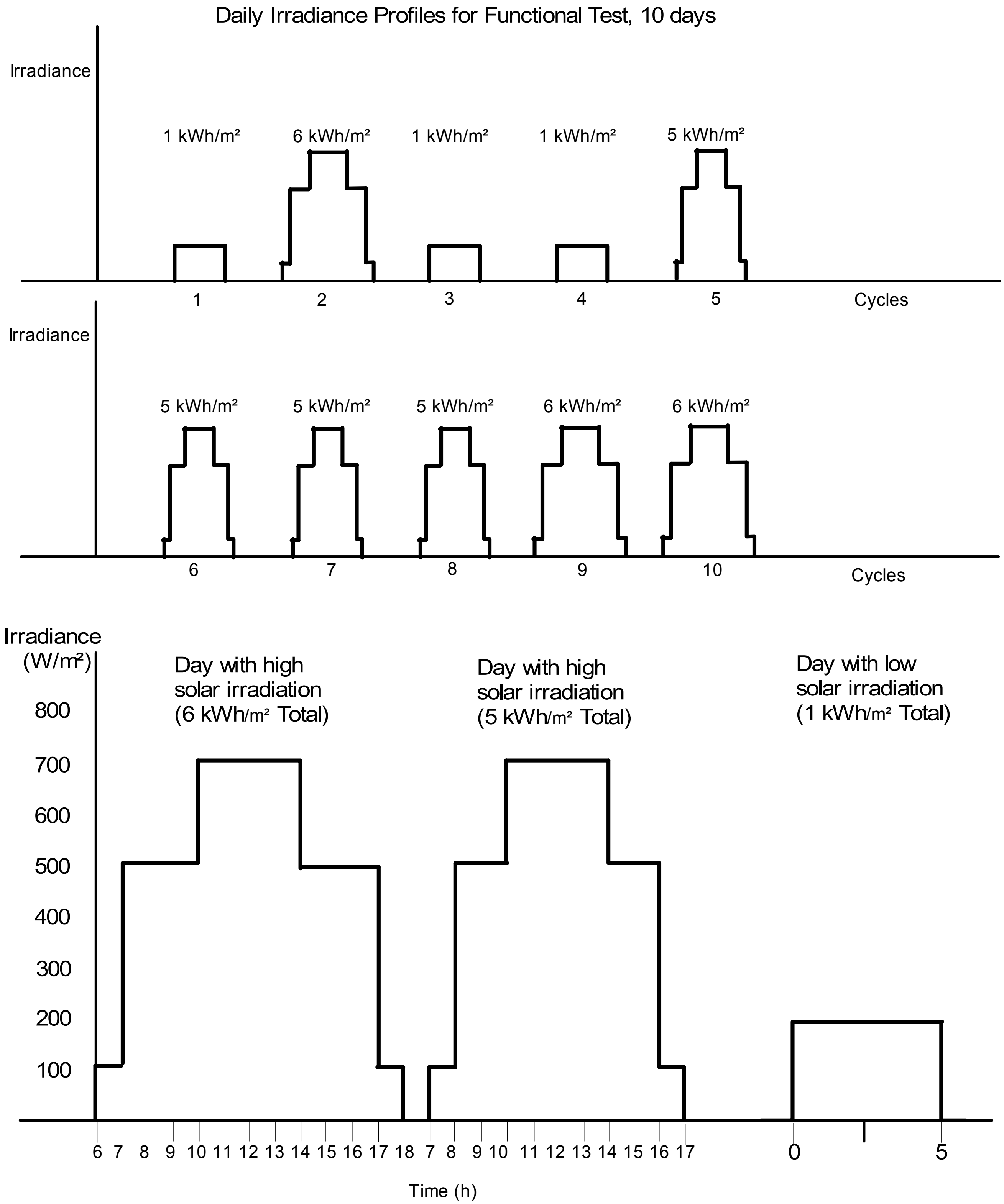


Figure 3 Recommended Irradiance Profile to be Used in Test

Table 2: Cycles of the performance test

Cycle #	Irradiance profile
Cycle 1:	Day with low irradiation (1 kWh/m²), operate load
Cycle 2:	Day with high irradiation (6 kWh/m²), operate load
Cycle 3:	Day with low irradiation (1 kWh/m²), operate load
Cycle 4:	Day with low irradiation (1 kWh/m²), operate load
Cycle 5:	Day with high irradiation (5 kWh/m²), operate load
Cycle 6:	Day with high irradiation (5 kWh/m²), operate load
Cycle 7:	Day with high irradiation (5 kWh/m²), operate load
Cycle 8:	Day with high irradiation (5 kWh/m²), operate load
Cycle 9:	Day with high irradiation (6 kWh/m²), operate load
Cycle 10:	Day with high irradiation (6 kWh/m²), operate load

The cycles do not necessarily have to cover 24 hours, since no rest time between operation of the load and the PV charging is required.

The irradiation profiles in Table 3 are minimum requirements that must be applied, better (smoother) profiles leading to a similar daily sum are also allowed:

Table 3 Irradiance profiles

Day with high solar irradiation (6 kWh/m²day +/- 0.3 kWh/m²)
1 hour at 100 W/m²
3 hours at 500 W/m²
4 hours at 700 W/m²
3 hours at 500 W/m²
1 hour at 100 W/m²

Day with high solar irradiation (5 kWh/m²day +/- 0.3 kWh/m²)
1 hour at 100 W/m²
2 hours at 500 W/m²
4 hours at 700 W/m²
2 hours at 500 W/m²
1 hour at 100 W/m²

Day with low solar irradiation (1 kWh/m²day +/- 0.3 kWh/m²)
5 hours at 200 W/m²

Perform a visual inspection in accordance with clause 15.4.

16.5 Second capacity test plus autonomy test

Disconnect the load after the functional test. Set the simulator at 700 W/m² ± 50 W/m². With PV on and light off recharge the battery until it has reached regulation (HVD) and stays there for a maximum of 0.5 hours. Disconnect the PV module and switch on the light. Allow the lantern to discharge the battery until it reaches LVD.

Determine the lantern autonomy.

Determine the number of Ah discharged from the battery and the total time to discharge. This is the Second Usable Battery Capacity (UBC_2).

Allow the battery to remain at LVD for at least 5 hours but not more than 72 hours.

Perform a visual inspection in accordance with clause 15.4.

16.6 Recovery test

Connect the PV module and switch off the light. Operate the solar simulator with an irradiance profile of a day with high solar irradiation (5 kWh/m²) in accordance with clause 16.4. Then connect the load as specified by the manufacturer in accordance with clause 10.

> Note: The lantern may still have low-voltage protection at this time. If that is the case, disconnect the load again and operate the solar simulator with an irradiance profile of a day with high solar irradiation (5 kWh/m²) in accordance with clause 16.4. Then connect the load as specified by the manufacturer in accordance with clause 10.

Once the load comes on, wait until the lantern reaches LVD or the Daily Run Time has passed.

Repeat this test until the lantern has gone through seven recovery test cycles. The lantern has then been exposed to an overall irradiation of 3.5 kWh/m². If the lantern reaches HVD, record after how many recovery test cycles HVD was reached.

Record at which “recovery test cycle” the load started to operate.

Measure the net Ah into the battery and to the load during seven recovery test cycles.

After these recovery test cycles switch off the light, set the simulator at 700W/m² ± 50W/m² and wait until the lantern reaches a state of regulation. Once the lantern reaches a state of regulation, keep it at this state for 12 hours. The battery can then be regarded as fully charged.

Perform a visual inspection in accordance with clause 15.4.

16.7 Final capacity test

With PV off and light on continuously, allow the lantern to fully discharge the battery. The battery is fully discharged when it reaches LVD. Allow the battery to remain at LVD for 5 hours. Record the number of Ah discharged from the battery. This is the Final Usable Battery Capacity (UBC_2).

16.8 Operation at maximum voltage

Verify the suitability of the light operated at the maximum battery voltage occurring during periods of high irradiance (between 800 and 1000 kWh/m²) and at high state of charge. The light shall be operated for a period of 1 hour under these conditions. The light shall operate undamaged.

> Note: there are lanterns on the markets that have a built-in automatic protection mechanism, preventing simultaneous charging of the battery and use of the lamp. For such lanterns this test cannot be carried out.

16.9 Visual inspection

Perform a visual inspection in accordance with clause 15.4.

16.10 Unusual occurrences

Note any unusual occurrences during the test period. These may include unplanned short or open circuits, data acquisition system malfunctions, and so on.

17 Determination of the System Balance Point

The lantern characterization plot gives a graphical representation of the minimum average irradiation that the intended location must have for the lantern to function properly.

Sum the Ah into the battery and the irradiation for each day during the functional and recovery tests. Plot the battery Ah along the Y-axis vs. irradiation along the X-axis.

The data should tend to fall along and in between two lines similar to those shown in example in Figure 4.

A horizontal line is drawn through the point with the minimum value of Ah for days when the charge controller limits the module current flowing into the battery. A sloped line is drawn through origin and the point with the highest value on days the controller does not limit the current flowing into the battery at any time. The System Balance Point is defined by the intersection of these lines.

The System Balance Point can be determined by calculation or by using graphical means.

The system as shown in Figure 4 will, for example, be suitable for locations that have at least 2.5 kWh/m²·day as a yearly average. Therefore the lantern would be qualified for irradiation class I (Annex A) and the specified daily load profile (Daily Run Time) which must be stated in the final test report and should correspond with the manufacturer's lantern performance declaration.

Note: A different load profile results in different characterization chart.

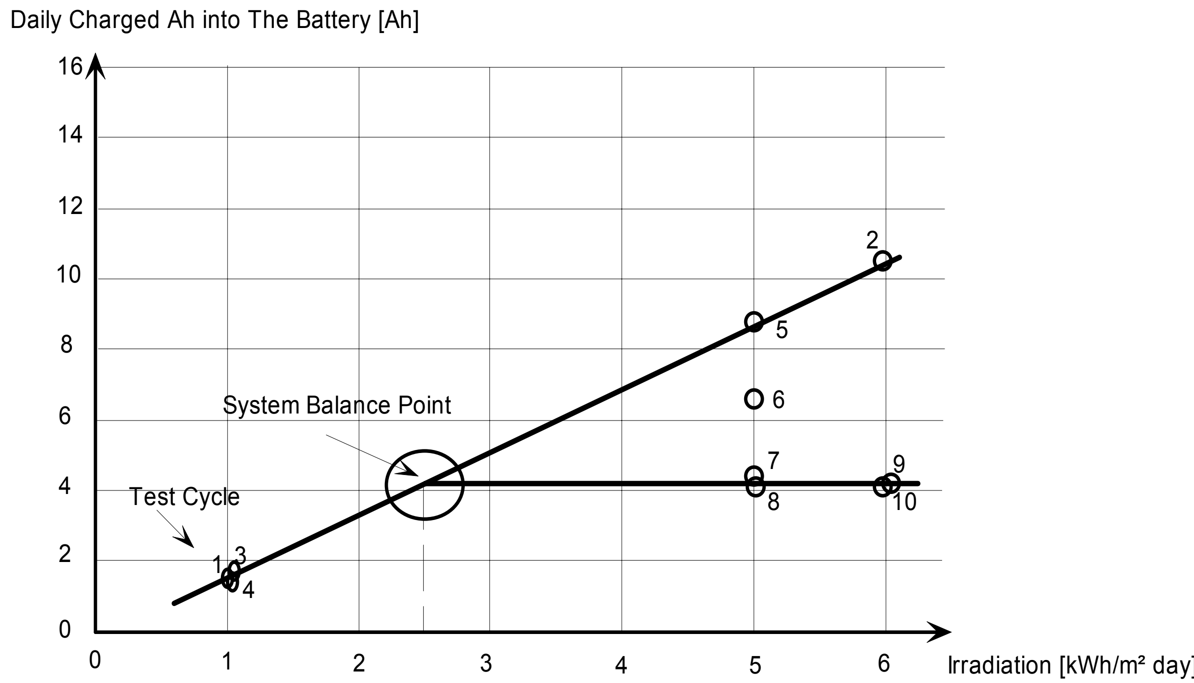


Figure 4 Lantern characterization chart, charge sequence example with three irradiation profiles and 10 cycles. Discharge: constant load profile.

18 Indoor testing using a PV module simulator

18.1 Testing conditions

An electronic power supply simulating the module characteristics shall be used, which has the ability to simulate the Reference Solar Day in accordance with clause 16.4.

Annex C describes the calculations leading to current and voltage characteristics simulating the PV module under conditions prescribed in this specification.

The temperature of the batteries shall be kept at 27°C ± 3°C.

The general ambient temperature during testing shall be within 27°C ± 3°C.

18.2 Initial capacity test

Perform this test in accordance with clause 16.2.

18.3 Battery charge cycle

Perform this test in accordance with clause 16.3.

18.4 Lantern functional test

Perform the functional test in accordance with clause 16.4.

18.5 Second capacity test

Perform this test in accordance with clause 16.5.

18.6 Recovery test

Perform this test in accordance with clause 16.6.

18.7 Final capacity test

Perform this test in accordance with clause 16.7.

18.8 Operation at maximum voltage

Perform this test in accordance with clause 16.8

18.9 Visual inspection

Perform a visual inspection in accordance with clause 15.4.

18.10 Unusual occurrences

Note any unusual occurrences during the test period. These may include unplanned short or open circuits, data acquisition system malfunctions, and so on.

19 Modifications

Any change in the design, materials, components or processing of the lantern may require a repetition of some or all of the qualification tests to maintain design qualification.

20 Report

A report of the qualification tests, with measured performance characteristics and details of any failures and retests, shall be prepared by the testing laboratory. The manufacturer shall keep a copy of this report for reference purposes.

Annex A (Normative)

Classification of Irradiation and Systems

A.1 Determination of the irradiation class and design irradiation

Derive the *Yearly Average Daily Horizontal Irradiation* and the *Irradiation Range* from a meteorological station near the location of intended use.

The *Irradiation Range* (H_{range}) is the difference between the *Monthly Average Daily Horizontal Irradiation* of the months with the highest and lowest irradiation (in kWh/m²·day).

Table A-1 contains a classification system for locations with different irradiation patterns.

Every location can thus be allocated to an *Irradiation Class*.

Table A-1: Irradiation Classes

Irradiation Class	I	II	III	IV	V	VI
Yearly average daily horizontal irradiation [kWh/m²·day]	<4.5	<4.5	4.5 - 5.5	4.5 - 5.5	>5.5	>5.5
Range [kWh/m²·day]	>1.5	<1.5	>1.5	<1.5	>1.5	<1.5

Note: The calculation of the DRT is based on Irradiation class III.

A.2 Rating systems

For a given system at a specific location, the *Effective Daily Energy Available to the Load* can be calculated. This will then be expressed as the *Effective Daily Energy Available to the Load* for a system of make X at location Y and shall be expressed in Wh. The same system may be classified differently in another country, or even at another location in the same country.

Annex B (Normative)

Instrumentation and equipment for the system test.

The following instrumentation and equipment is necessary for conducting the system tests:

- DC voltage and DC current measuring instruments
- DC amp-hour meter or some other means of monitoring
- Elapsed time meter or some other means of monitoring
- A PV reference device that has been selected and calibrated in accordance with IEC 60904-2 to match the test modules regarding the spectral response
- Suitable instrumentation to check that the reference device and the module are co-planar to within ± 5°
- Temperature sensors
- A means to identify orientation
- Automated data acquisition system to facilitate system monitoring during the test

Data acquisition system specifications

The datalogger shall use at least a 12 bit analog-to-digital converter and have an input range that exceeds the expected positive and negative maximum voltages. The data acquisition system must be reliable: if more than 4 hours of data is lost or if any critical data is lost owing to a power failure during any test, then that test shall be restarted.

The sample rate of the datalogger is dependent on the type of charge controller. For on-off controllers, the datalogger sample rate shall be at least two times as fast as the switching period of the controller. For example, if the operation of the regulation voltage circuitry is every 10 seconds, the sample rate shall be once every 5 seconds, or faster.

For charge controllers using constant-voltage or pulse-width-modulation circuitry, the switching period may be milliseconds, not seconds. The sampling rate of the datalogger should be at least twice the switching frequency of the charge controller. If the sample rate of the used datalogger is not fast enough, one method is to sample once per second with an integrator/filter circuit added to the data acquisition system input. The time constant of the integrator/filter will need to be at least two times the sample period.

An oscilloscope may be required to determine the controller type and its switching frequency.

Data shall be stored as 5 minute averages as appropriate for each test.

The parameters shown in Table B-1 shall be measured or determined:

Table B-1. Parameters to be Measured/Determined

Measured parameter	**Recorded Values**	**Comments**
Module voltage Load voltage Battery voltage	Minimum, average and maximum Minimum, average and maximum Minimum, average and maximum	Voltage at the module, before blocking diodes Measured at the load Measured at the battery
Module current Load current Battery current	Minimum, average and maximum Minimum, average and maximum Battery amp-hours in and out	
Air temperature Module temperature Battery temperature	Average Average Average	 Use IEC 60904-5 At temperature compensation sensor or negative battery terminal
Solar irradiance Load operation	Average Load run time	Reference device, short circuit current and temperature of device

Sensor specifications

The voltage sensors shall have a range exceeding the maximum expected voltage and the measurement shall have a resolution of 0.01 V or better. The current sensors shall have a range exceeding the expected maximum positive and negative current and the measurements shall have a resolution of 0.01 A or better.

DC voltage and DC current measuring instruments shall comply with IEC Publication 60904-1, except that the accuracy shall be within ± 1% Full Screen (FS).

The temperature sensors shall have a range exceeding the expected maximum positive and negative system and ambient temperatures and measurement resolution of 1° C or better. The temperature measurement accuracy shall be ±2° C or better.

The irradiance sensor shall have a suitable range and an accuracy of at least ±5 percent of the reading.

Annex C (Normative)

Determination of the module output for the indoor testing using a PV module simulator.

Note: Please be aware that certain PV module simulators may not be compatible with all types of charge controllers owing to the internal switching frequencies.

C.1 Constant current source simulation

The flow diagram (Figure C-1) explains the steps to be taken to arrive at appropriate settings for a constant current source simulating the PV module:

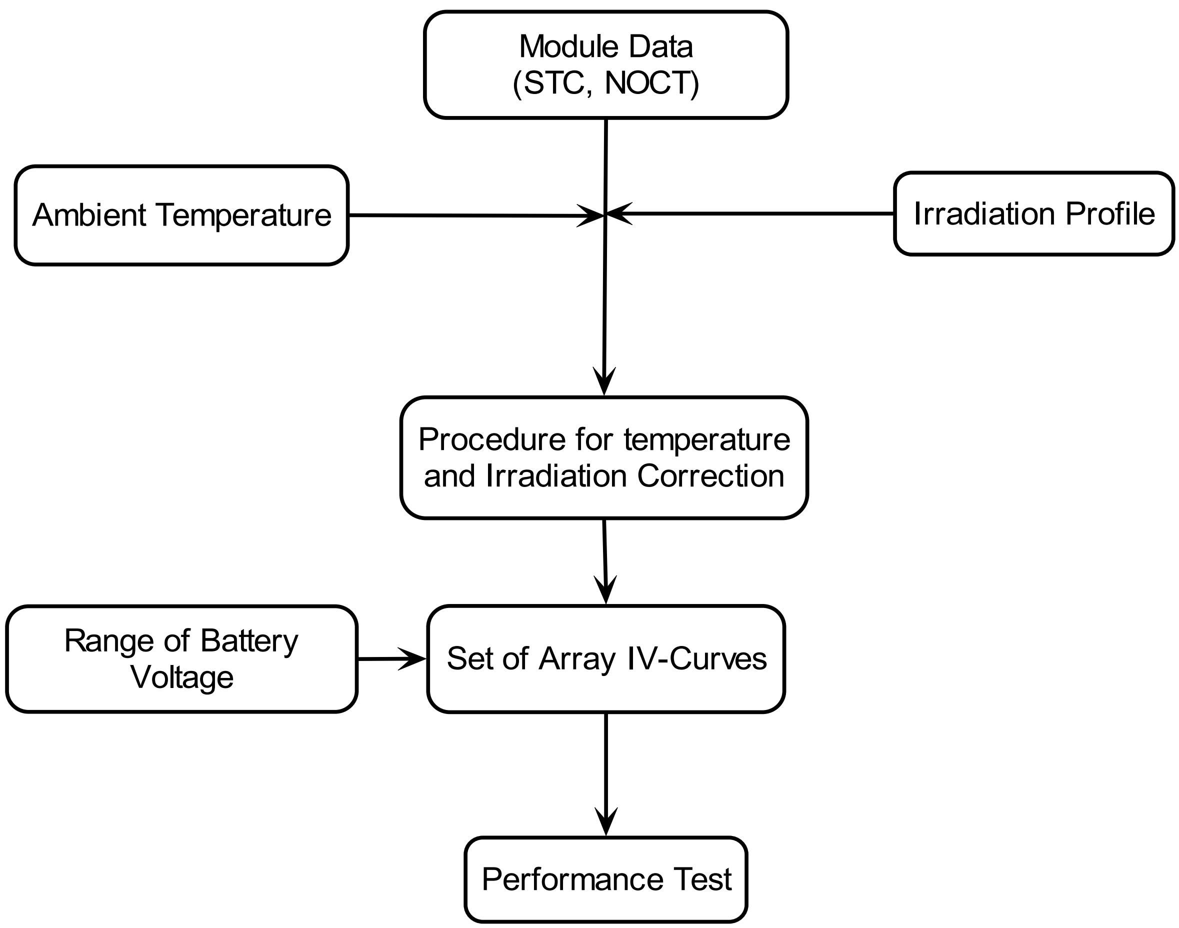


Figure C-1 Flow Diagram

Assuming the NOCT of the module is determined, only the performance of the module under STC shall be measured (refer to module performance data).

The output corresponding to the conditions at the defined reference solar day has to be calculated according to the following formula:

Translation factors

$$I_{SC,2} = I_{SC,1} \cdot \left[1 + \alpha \cdot (T_2 - T_1)\right] \cdot \frac{G_2}{G_1}$$

$$V_{OC,2} = V_{OC,1} \cdot \left[1 + a \cdot \ln\frac{G_2}{G_1} + b \cdot (T_2 - T_1)\right]$$

Translation equations for the IV data points

Current: $I_2 = I_1 \cdot \left(\frac{I_{SC,2}}{I_{SC,1}}\right)$

Voltage: $V_2 = V_1 + (V_{OC,2} - V_{OC,1}) + R_S \cdot (I_1 - I_2)$

Module parameters

α	: dimensionless temperature coefficient of I_{SC}	(default =0.0005 /°C)
b	: dimensionless temperature coefficient of V_{OC}	(default=-0.004 /°C)
a	: dimensionless radiation correction factor of V_{OC}	(default=0.06)
R_S	: serial resistance of the module, PV array	(default=0)

C.2 Temperature and irradiance correction of current-voltage characteristics

As a result of the procedure for temperature and irradiance correction a set of IV-curves is defined according to the specified reference solar day. One curve for each step of the day profile is estimated. This procedure must be repeated for every profile which is used in the test sequence of the performance test. See Figure C-2.

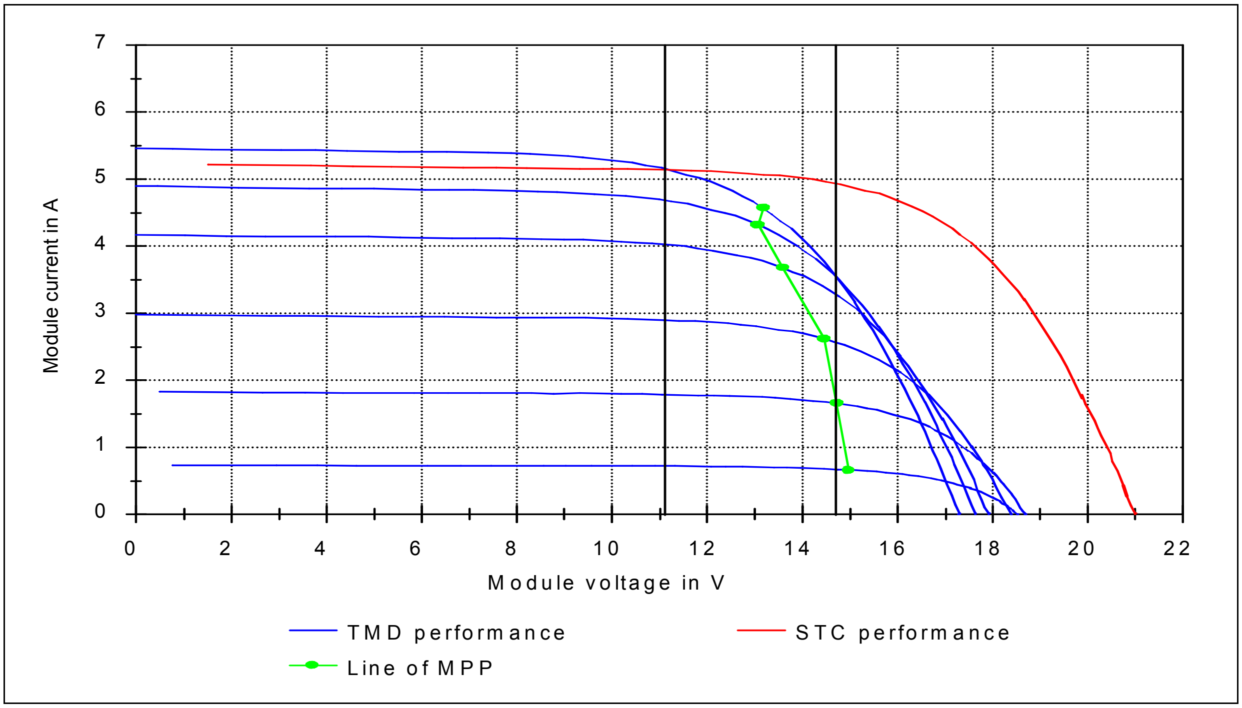


Figure C-2: Set of IV characteristics for a daily irradiance profile (example) [TMD – typical mean daily; MPP – maximum power point]

The solar lantern voltage is dominated by the battery voltage and therefore the module operates in the range of the battery voltage. The window is limited by two significant thresholds. The upper limit is the High Voltage Disconnect (HVD) set-point which disconnects the module at a certain voltage. The lower limit is the Low Voltage Disconnect point (LVD) which protects the battery and cannot be exceeded by normal system operation.

The IV-curves within the window can be estimated linearly. These estimated linear lines are called operation lines. Each IV curve within the battery voltage range is defined by means of two operation lines to achieve a good estimation. The operation lines are defined by three points on the IV-curve. The point of intersection between the module IV-curve and the lower voltage limit is the first point (Lx). The second point (Mx) is at the middle of the defined voltage range. The point of intersection between the module IV-curve and the higher voltage limit is the third point (Hx). See Figure C-3.

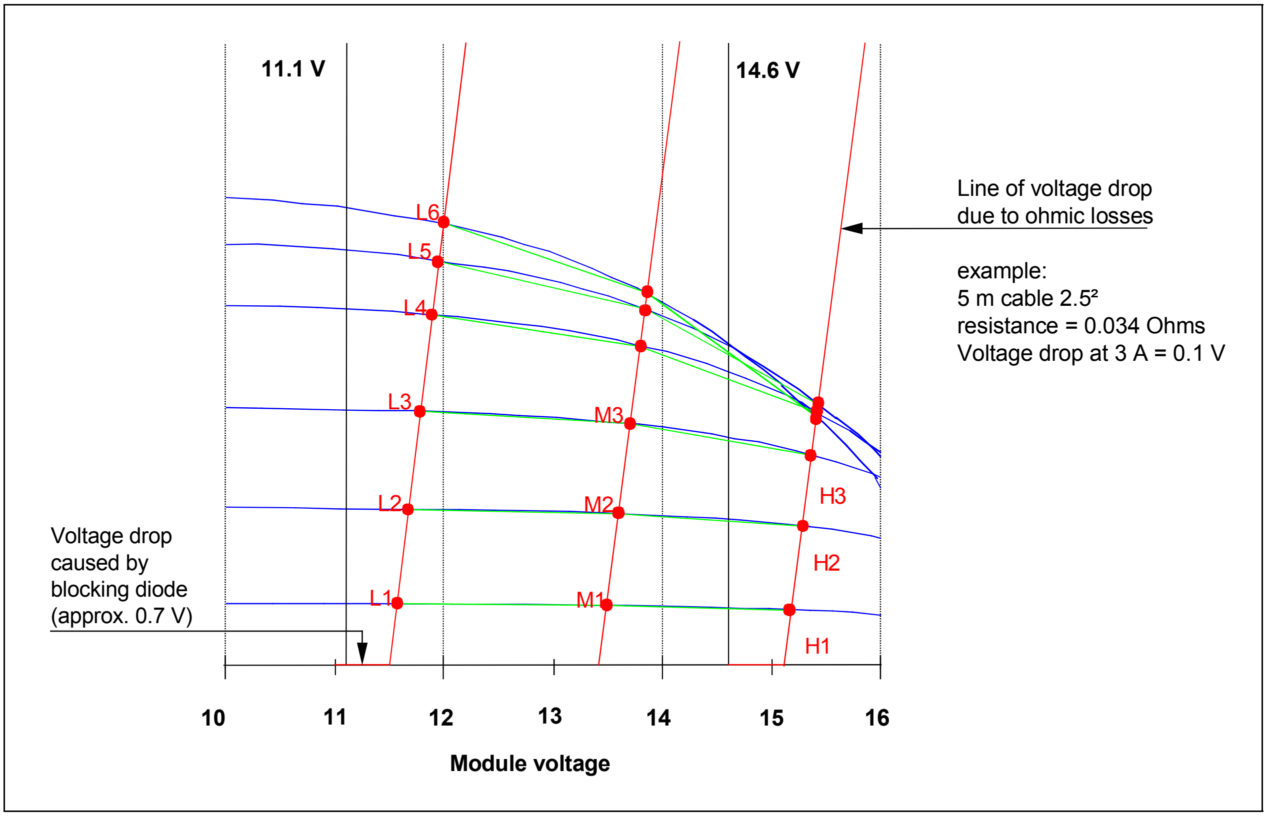


Figure C-3 Approximation of module characteristics by a set of module operation lines

Note: The vertical line at 11.1 V is the Low Voltage Disconnect (LVD) and the vertical line at 14.6 V is the High Voltage Disconnect (HVD) set-point of the charge controller. Different charge controllers have different set-points.

C.3 Module simulation procedure

The electrical behavior of the module can be simulated by means of a programmable constant current source.

Charging of the battery is controlled by the processing unit. The inputs are the- current-voltage co-ordinates for the linear approximation of the module characteristics and the battery voltage and the output is the module current.

Depending on the measured battery voltage, the current is changed continuously by successive approximation steps until the current-voltage operation point fits with the module operation line. See Figure C-4.

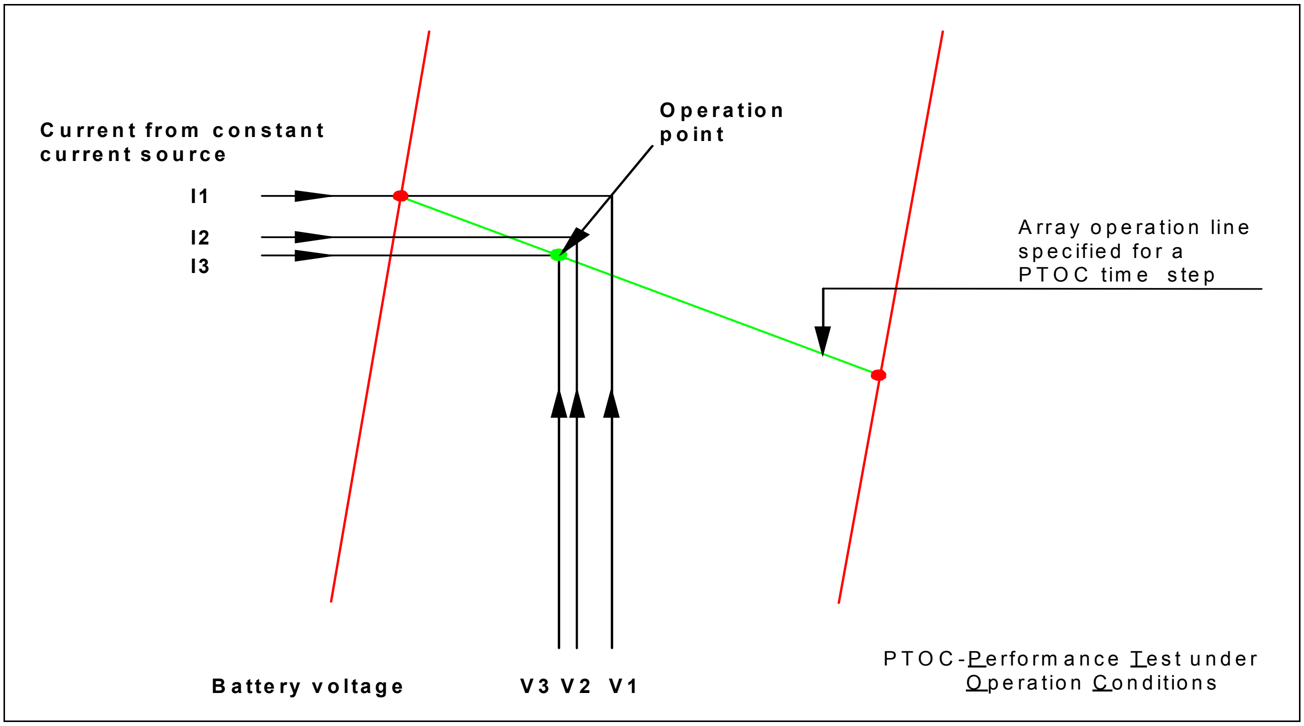


Figure C-4 Iteration process for current adjustment

C.4 Set-up for testing

The lantern without module(s) shall be installed in a climatic chamber (in case the charge controller uses a separate temperature sensor, it is possible to place only the battery in a climatic chamber or a bath). See Figure C-5.

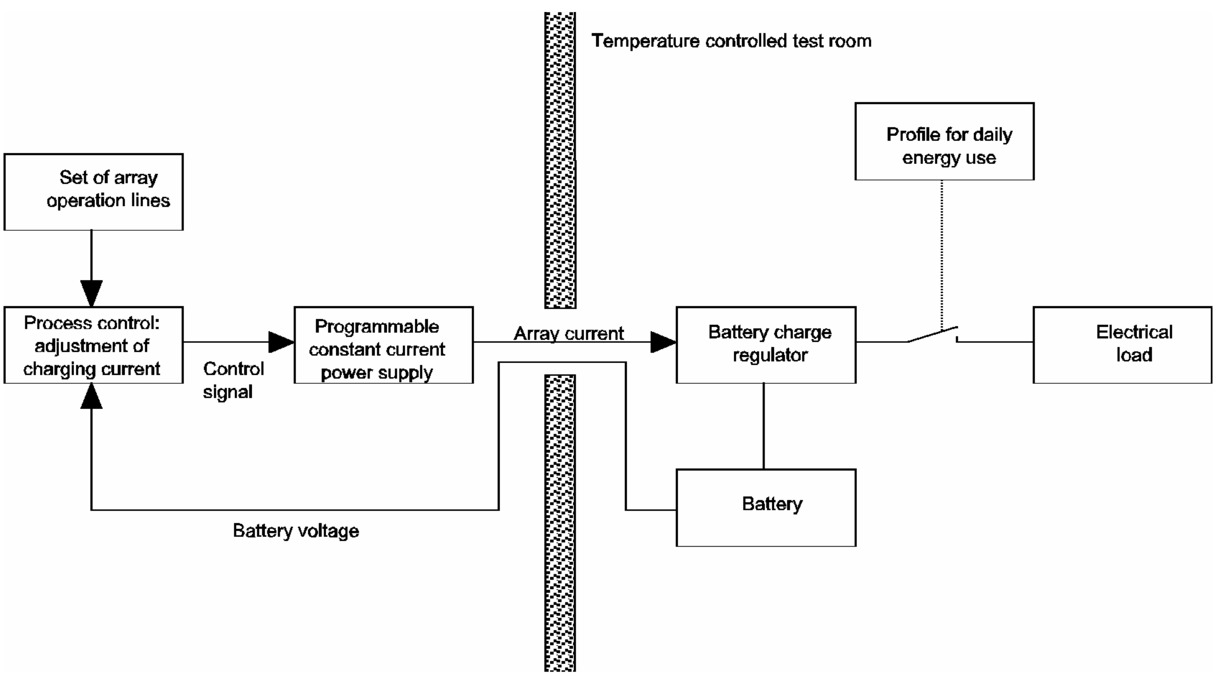


Figure C-5 Experimental set-up for PV system performance testing

C.5 Algorithm for simulation of the module performance

Flow chart for simulation of the module performance presented for one time step of the PTOC profile. See Figure C-6.

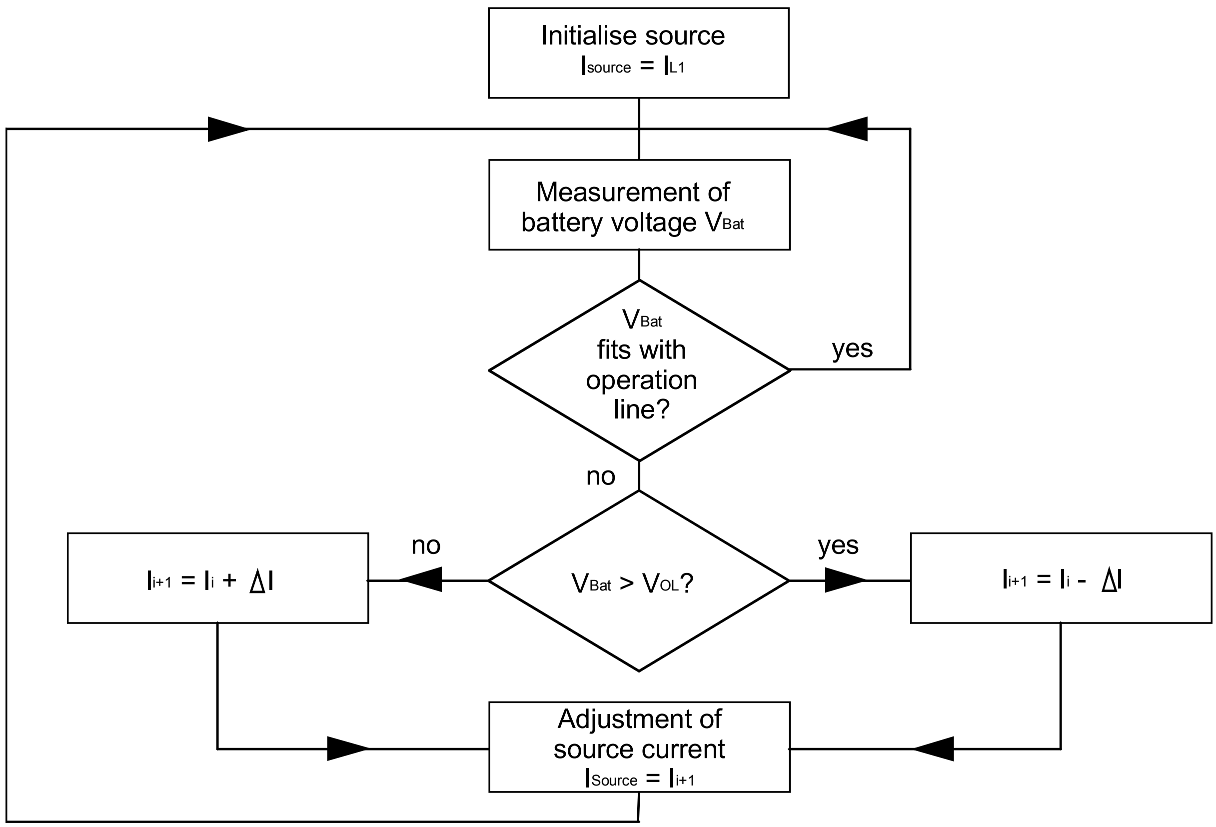


Figure C-6 Flow chart for simulation of the module performance

Annex D (Informative)

Design Recommendations

The following recommendations represent current best-practice design recommendations for portable solar PV lanterns are summarized below.

D.1 Reverse current

Reverse current, that is, the battery discharge into the module(s), should be minimized. The means by which this is achieved should be documented. If blocking diodes are used, the current capacity should be 50 percent higher than the short circuit current (at STC). The peak inverse voltage of the diode should be at least double the open circuit battery voltage.

D.2 Quiescent current

The quiescent current, that is, the self-consumption when no lamp is lit, should not exceed 2.0 mA.

D.3 Protection against dust, water and foreign bodies (IP-code)

Since the solar lanterns are predominantly used indoors, but may be taken outdoors occasionally and hence may be subjected to occasional rainfall, a minimum IP class of IP23 (see IEC 60529) is recommended. This also ensures a desired level of safety with regard to accidental accessibility of live parts.

D.4 Cable

A water resistant, mechanically robust and UV resistant cable should be used between the solar PV module and the charge controller. A cable at least 5 meter long should be provided for inter-connection between the module and the lantern

The continuous maximum current rating of the conductors (after any deratings for temperature or installation conditions) in the PV source and output circuits should be at least 156 percent of the short circuit current (at STC) and should not be less than the rating of any overcurrent device protecting those conductors.

All wiring should be color coded and/or labeled.

D.5 Connectors

All connectors should be polarized and be able to withstand 156 percent of the short circuit current at STC.

The rated current-carrying capacity of the connectors should not be less than the circuit current rating.

D.6 Indicators

The lantern should provide an indication of charging state, and an indication of load-disconnect state. The indicator may consist of LEDs or an LCD display.

D.7 Switching thresholds for charge controllers for lead-acid batteries

The following thresholds are recommended for using the battery voltage as the main parameter for the switching algorithm, at a surrounding temperature of 20 °C and an acid concentration of 1.24 kg/l:

- High Voltage Disconnect (HVD): > 2.35 V/cell
- High Voltage Reconnect by two-point regulation (HVR): 2.15-2.35 V/cell
- Low Voltage Disconnect (LVD): ≥ 1.90 V/cell
- Low Voltage Reconnect (LVR): ≥ 2.15 V/cell

At other acid concentrations, the required thresholds must be adjusted according to the manufacturer's specifications.

Note 1: The lower limit of the Low Voltage Disconnect is an absolute minimum.

Note 2: These values are primarily intended for charge controllers that use the battery voltage as the main parameter for the switching algorithm. Some manufacturers use other parameters, such as state of charge.