Solar Photovoltaic Energy Systems Sectional Committee ET 28

. FOREWORD

This Indian Standard (Part 2) is proposed to be adopted by the Bureau of Indian Standards, after the draft finalized by the Solar Photovoltaic Energy Systems Sectional Committee has been approved by the Electrotechnical Division Council.

This draft standard covers test methods for portable LED based solar lanterns, which are lighting systems consisting of white LEDs as a light source, a storage battery (Sealed Maintenance Free lead-acid or nickel-metal hydride (NiMH) or Lithium based battery or other) and electronics, all placed in a suitable housing made of durable material such as metal or plastic and a separate PV module. The battery is charged by electricity generated through the PV module through a charge controller. 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 enclosure to protect it from direct rain, sun, wind-blown dust, fungus etc. These solar lanterns can either be charged through individual solar panel or through centralized solar charging station.

This standard has been dealt within two parts, one exclusively on the specification and the other on methods of test.

Considerable assistance has been derived from IEC/TS 62257-9-5 (2013) in the preparation of this standard.

In reporting the result of a test or analysis made in accordance with this standard, is to be rounded off, it shall be done in accordance with IS 2 : 1960 ‘Rules for rounding off numerical-values (revised)’.

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BUREAU OF INDIAN STANDARDS
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Draft *Indian Standard*

LED BASED SOLAR LANTERN
PART 2 METHODS OF TEST

Last date for receipt of comments is_____**12-11-2013**

1. SCOPE

This draft standard lays down test methods for portable LED based solar lanterns, which are lighting systems consisting of white LEDs as a light source, a storage battery (Sealed Maintenance Free lead-acid or nickel-metal hydride (NiMH) or Lithium based battery or other) and electronics, all placed in a suitable housing made of durable material such as metal or plastic and a separate PV module. The battery is charged by electricity generated through the PV module through a charge controller. 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 enclosure to protect it from direct rain, sun, wind-blown dust, fungus etc. These solar lanterns can either be charged through individual solar panel or through centralized solar charging station

2. NORMATIVE REFERENCES

Following Standards are necessary adjuncts to this standard:

IS No.	*Title*
12762(Part 1):2010	Photovoltaic Devices Part 1 Measurement of Photovoltaic Current- Voltage Characteristics
16047:2012	Secondary Cells and Batteries containing Alkaline or other non-acid Electrolytes - Secondary Lithium Cells and Batteries for Portable Applications
16048(Part 1): 2013	Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes - Portable Sealed Rechargeable Single Cells Part 1 Nickel-Cadium
16048(Part 2):2013	Secondary Cells and Batteries Containing Alkaline or Other Non-Acid Electrolytes-Portable Sealed Rechargeable Single Cells Part2 Nickel-Metal Hydride

3. TERMINOLOGY

For the purpose of this standard, the following terminology shall apply:

3.1 Capacity of a Cell or a Battery — The quantity of electricity (electric charge), usually expressed in ampere-hours (Ah), which a fully charged battery can deliver under specified conditions

3.2 Life of a Lamp — The total time for which a lamp has been operated before it becomes useless, or is considered to be so according to specified criteria

Note 1— to entry Lamp life is usually expressed in hours.

3.3 Light Unit — Assembly inside a casing of all parts such as lamps, optical apparatus, coloured glass,terminals, necessary to exhibit a light aspect

3.4 LED based Solar Lantern — Solar photovoltaic (PV) based lanterns (SL), which are lighting systems consisting of white LEDs as a light source, a storage battery (Sealed Maintenance Free lead-acid or nickel-metal hydride (NiMH) or Lithium based battery or other) and electronics, all placed in a suitable housing made of durable material such as metal or plastic and a separate PV module. The battery is charged by electricity generated through the PV module through a charge controller.

3.5 L**ux** — SI unit of illuminance: illuminance produced on a surface of area 1 square metre by aluminous flux of 1 lumen uniformly distributed over that surface

3.6 Ampere symbol A— SI unit of electric current, equal to the direct current which, if maintained constant in two straight parallel conductors of infinite length, of circular cross-section with negligible area, and placed 1 metre apart in vacuum, would produce between these conductors a force per length equal to 2×10^{-7} N/m

Note — CGPM definition is as follows: "The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible circular cross-section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to 2×10^{-7} newton per metre of length."

3.7 Multimeter — Multirange multifunction measuring instrument intended to measure voltage, current and sometimes other electrical quantities such as resistance

3.8 A**mmeter**— Instrument intended to measure the value of a current

3.9 Voltmeter — Instrument intended to measure the value of a voltage

3.10 Integrating Sphere — Hollow sphere whose internal surface is a diffuse reflector, as non-selective as possible. Used to determine the total luminous flux (lumen output) of a lighting device

Note 1 to entry — An integrating sphere is used frequently with a radiometer or photometer.

3.11 Power Supply — Electric energy converter which draws electric energy from a source and supplies it in a specified form to a load

3.12 Overvoltage Protection — Protection intended to operate when the power system voltage is in excess of a predetermined value

3.13 Portable — Products or subsystems are portable when two or more of the main components (energy source, energy storage, and light source) are connected in a way that makes the product or subsystem easy for an individual to carry

3.14 Light Emitting Diode LED — solid state device embodying a p-n junction, emitting optical radiation when excited by an electric current

3.15 Low-Voltage Disconnect LVD —Battery voltage at which the load terminals of the charge controller are switched off to prevent the battery from over discharging

4. VISUAL SCREENING

4.1 Background

The visual screening process covers the Solar Lantern(SL) specifications, properties (such as external SL measurements), functionality, observations, and internal/external construction quality.

The SL's components, materials, and utilities are categorized and, in some cases, evaluated. This test provides a thorough qualitative and quantitative assessment of the SL as received from the manufacturer and serves to uniquely identify a SL. The SL's operation out of the packaging is documented before any modifications are made for subsequent tests.

4.2 Test outcomes

The test outcomes of the visual screening process are listed in Table 1.

Table 1.Visual screening test outcomes
(Clause 4.2)

Sl. No. (1)	Metric (2)	Reporting units (3)	Notes (4)
i)	SL specifications	Varied	Record all provided specifications
ii)	SL information	Varied	Record dimensions and qualitative descriptors
iii)	Internal SL inspection	Varied	Describe/document wiring and electronics fixtures
iv)	Internal SL inspection	Number of defects	Record the number of soldering and/or electronics quality defects

4.3 Procedure

4.3.1 *Properties, Features, and Information*

Relevant SL information, such as external SL measurements and observations, are recorded to capture the SL's characteristics. Sufficient comments should be provided to thoroughly describe the SL's characteristics. This part of the procedure can be completed on a single sample.

4.3.1.1 *Equipment requirements*

Callipers and/or ruler

Balance (scale)

Bright task light with an intensity of 500 lux

4.3.1.2 *Test prerequisites*

The SL should be new, unaltered, and in its original packaging. Read the SL's box and documentation for instructions on using the SL. Ensure the SL's battery is fully charged prior to conducting the test.

4.3.1.3 *Apparatus*

The SL to be positioned under a bright task light for examination.

4.3.1.4 *Procedure*

a) Provide the following:

   1) Note all available manufacturer contact information (e.g. name, address, phone number, email and website etc.)
   2) See if a user's manual is included with the SL. If so, report the type of manual it is (e.g. booklet, sheet, etc.), report the language(s) in which it is written
   3) If a warranty is available for the SL, record the warranty duration, in months, describe the terms and conditions, and photograph the warranty material.

b) Observe the following

   1) Determine the number of SL light output settings. Use the setting descriptions provided by the SL's literature. If no setting descriptions are provided, use appropriate descriptions (e.g., high, medium, low, 1 high-power LED, 2medium power LED,3 low-power LEDs, etc.).
   2) Describe the materials that compose the SL's lamp units, battery housing, charge controller housing, and/or any other housings (e.g., plastic, metal, glass, or other).
   3) Note the number of indicators in the SL (e.g. charge indicator and load cut off indicator), include descriptions of indication meanings.
   4) Note whether the charging indicator is true charging indicator or deceptive.
   5) Note any other features present on or included with the SL (e.g. handles, mounting brackets, stands, etc.).
   6) Note if the SL has a radio or mobile phone charging capabilities. If so, photograph the connectors.
   7) Describe any other included accessories or connectors
   8) Indicate if the SL provides central (e.g., grid, central station, etc.) or independent (e.g., mechanical, solar PV, etc.) charging and the specific charging means and describe the robustness of each included charging mechanism.

c) Measure and observe the following (in the provided unit) for the SL's PV module:

1) Measure the PV module's overall length and width, in centimetres (cm), including the frame.
2) Note that the module manufacturer name/logo, model number, serial number and year of make are laminated inside the module
3) Measure the PV module's cable length, in meters (m), in the case of external PV modules.
4) Note if the SL can be turned on while it is being charged with its PV module.
5) Provide any general comments regarding the SL's properties, features, and/or information.

4.3.2 *Specifications*

All relevant SL specifications are recorded for later comparison in testing results. This part of the procedure can be completed on a single sample.

4.3.2.1 *Test prerequisites*

The SL should be new, unaltered, and in its original packaging. Read the SL's box and documentation for instructions on using the SL. Consult the manufacturer for missing information pertaining to the required observations.

4.3.2.2 *Procedure*

Examine the SL's packaging, user's manual, and components for battery, lamp, charge controller, and PV module specifications. While obtaining the specifications, the SL should not be opened or otherwise tampered with in any way. The internal inspection of SL may reveal more product specifications, which should be included with the specifications from this section and noted accordingly.

a) Note the following specifications (in the specified units), indicate and comment on any specification discrepancies. Indicate if the specification is not provided but can be ascertained by observation (e.g., battery chemistry and nominal battery voltage):

1) Battery chemistry (SLA, NiCd, NiMH, Li-Ion, $LiFePO_4$, or specify other)
2) Rated battery capacity, in milliamp hours (mAh)
3) Nominal battery voltage, in volts (V)
4) Make number and wattage of LEDs used in the system.
5) LED driver buck or boost type
6) Charge controller charging algorithm (Series regulated, shunt regulated, constant voltage, constant current or PWM type)
7) Charge controller deep discharge protection voltage, overcharge protection voltage and load
8) reconnect voltage in volts (V)
9) Wattage of the PV module W
10) I-V curve of the PV module along with all the parameters

b) record the following run time specifications, in hours (h), indicate and comment on any discrepancies:

1) Note the number of hours of operation on a full battery charge for all lamp settings (full-battery run time).

2) Note the number of hours of operation on a battery charge from a day of solar charging for all lamp settings (daily solar run time).

3) Note the number of hours of operation after a specified mechanical charge period for all lamp settings (mechanical run time).

4) Note the number of hours of operation after a specified AC/DC adapter charge period for all lamp settings (grid run time).

5) Note and describe any specified run times that do not fit into the previous four categories.

6) Where available, note any light output specifications, in lumens (lm), indicate and photograph the source(s) of each, the corresponding lamp setting(s), and comment on any discrepancies.

4.3.3 *Functionality and Internal Inspection*

An internal inspection is performed to assess the electronics, soldering workmanship and for the connection of different components to be solder free. The SL can fail the inspection if poor internal workmanship inhibits the SL from properly functioning. This part of the procedure should be completed for every sample being tested.

4.3.3.1 *Equipment requirements*

a) Bright task light with an intensity of 500 lux

b) Miscellaneous hand tools (screwdrivers, wrenches, etc.) to disassemble the SL

c) Volt meter or multi-meter for conducting basic electronic integrity and functionality tests

4.3.3.2 *Test prerequisites*

The SL should be new, unaltered, and in its original packaging. Read the SL's box and documentation for instructions on using the SL. Consult the manufacturer for missing information pertaining to the required observations. If the SL's instructions require it to be fully charged prior to operation, do so prior to conducting this test. Ensure that the SL's battery is fully charged prior to conducting of test.

4.3.3.3 *Apparatus*

The SL should be positioned under a bright task light for examination.

4.3.3.4 *Procedure*

a) Check the SL's functionality before disassembling:

1) Does the SL work as described with provided documentation?

2) Do all of the SL's switches and connectors function as they should?

3) Comment on any faulty operation..

b) Disassemble the SL so the following internal observations can be made:

1) Indicate whether the SL uses the strain free cable

2) Inspect the electronic components' quality and workmanship. Note any poor solder joints, such as cold joints or joints with little solder. Document the workmanship with comments..

3) Indicate methods used to secure parts inside the SL (e.g., screws, glue, tape, clamps/straps, or other) and document it.

4) Indicate methods used for securing wire and cable connections (e.g., solder, harness, terminal junction, etc.) and document it.

5) Note if the SL has an easily replaceable battery and/or printed circuit board (PCB). The battery and PCB are easily replaceable if they can be interchanged without any tools other than screwdriver(s) (i.e., without soldering or splicing).

6) Examine the internal components, especially the battery, and note any specifications that were not apparent in the previous procedure

7) Note if the battery has an integrated battery circuit. This type of circuit is typically beneath a plastic jacket encasing the battery. Document it.

8) Note the SL's overall internal workmanship quality. Document the internal workmanship with descriptions.

4.4 Reporting

4.4.1 Report the following in the visual screening test report:

a) Report Date & time

b) SL manufacturer

c) SL name

d) SL model number

e) Name of test laboratory

f) Manufacturer contact information (e.g., website, email address, phone number, etc.)

g) User's manual information

   1) Included with SL (yes/no)

   2) Type (e.g., booklet, pamphlet, sheet, etc.)

   3) Language

   4) Comments

h) Warranty information, if available

   1) Length (months)

   2) Description of terms and conditions

j) Complete SL information (e.g., battery unit, lamp units, control unit, etc.)

   1) Mass (g)

   2) List of components included in mass measurement

k) SL cable information

   1) Length of all cables except those used to connect PV modules (m)

   2) Description of all cables except those used to connect PV modules

m) SL lamp unit technology information

   1) Make and total wattage of LEDs

   2) Number of Arrays and number of LEDs in each array

   3) Total number of LEDs

n) SL light output setting information

1) Name of all individual light output settings
2) Description of each individual light output setting

p) SL materials information

3) List of all materials used to construct each SL component (e.g., glass or plastic, etc.)
4) Description of all SL construction materials

q) SL indicators information

1) List of all indicators present on each SL component (e.g., battery charge indicator and
2) Load cut off indicator
3) Description of all SL indicators

r) SL auxiliary accessories information

a. Radio included (yes/no)
b. Mobile phone charging capability (yes/no)
c. Descriptions of other included SL's accessories and connectors

s) SL charging mechanism information

a. Central charging supported (yes/no)
b. Mechanical charging supported (yes/no)
c. Solar charging supported (yes/no)
d. Description of each included charging mechanism

t) SL PV module information

a. Length of each PV module (cm)
b. Width of each PV module (cm)
c. Manufacturer name/logo, model number, serial number and year of make laminated inside the module (yes/ no)
d. Form of each PV module (external or integrated)
e. Cable length of each PV module (m)
f. Active solar material of each PV module (e.g., mono-Si, amorphous, CIS, etc.)
g. Encasing of each PV module (e.g., lamination, glass, etc.)
h. Description of the robustness of each PV module
i. Description of PV module junction box workmanship
j. Other PV module information

u) Overall comments based on the visual inspection

v) Provided SL specification information, if available

a. Battery chemistry and source of information
b. Rated battery capacity (Ah) and source of information
c. Nominal battery voltage (V) and source of information
d. LED make and source of information
e. LED driver and source of information

f. Presence of charge controller (yes/no) and source of information

g. Charge controller deep discharge protection voltage (V) and source of information

h. Charge controller overcharge protection voltage (V) and source of information

i. PV module P_{max} (W_p), I-V curve along with module parameters and source of information

w) Description of any provided SL specification discrepancies

y) Provided SL run time information, if available

1) Full-battery run time (h) for each setting and source of information

2) Daily solar run time (h) for each setting and source of information

3) Mechanical run time (h) for each setting and source of information

4) Grid run time (h) for each setting and source of information

5) Other run time (h) for each setting and source of information

z) Description of any provided run time discrepancies

aa) Provided light output (lm) for each setting and source of information

bb) Description of any light output discrepancies

cc) SL functions out of box (yes/no)

dd) All switches and connectors function for each SL sample (yes/no)

ee) Description of strain free cable (Yes/No)

ff) Number of poor solder joints and workmanship deficiencies for each SL sample with comments as necessary

gg) Means (e.g., screws, glue, tape, etc.) used to secure parts in each SL component (e.g., lamp unit(s), charge controller, PV module(s), etc.)

hh) General fixture of parts comments

jj) Easily replaceable battery and PCB (yes/no)

kk) Comments on ease of battery and/or PCB replacement

mm) Overall description of internal workmanship

5. SAMPLE PREPARATION

5.1 Background

After visual screening the SL must be prepared before starting the tests. The preparation includes breaking the connections between the SL's battery and circuit in order to facilitate charging the product, powering the product with a laboratory power supply, as well as taking measurements.

5.2 Related tests

The sample preparation procedure must be performed on all SLs prior to conducting the testing

5.3 Procedure

5.3.1 *Sample Preparation*

The SL is rewired in order to make measurements of current and voltage during selected tests, charge the SL's battery via a battery analyser, and simulate a specified battery voltage during selected tests.

5.3.1.1 Equipment requirements

a) Wire (0.52 mm^2 or thicker)

b) Wire cutters

c) Wire strippers

d) Soldering iron and solder

e) Heat shrink and heat gun, or electrical tape

f) Screw drivers and/or other appropriate tools for opening the SL

g) May be required, depending on the SL, a power drill with an appropriately sized drill bit to make a hole in the SL's enclosure to fit four extension wires

5.3.1.2 Procedure

a) Open the SL, without incurring damage, such that its battery is exposed.

b) Identify the positive and negative terminals or leads on the SL's battery.

c) With wire cutters, cut the positive and negative wires individually where the SL's battery connects with the rest of the SL circuit. Cutting the wires together could cause an electric shock.

NOTES :

1) in some cases, a third wire is attached between the SL's battery and circuit for battery temperature monitoring – do not cut this wire, leave it as is.

2) In some cases, more than one wire is connected to the SL's positive battery terminal and/or more than one wire is connected to the SL's negative battery terminal – keep the wires attached to each terminal together and treat them as one wire end for the remainder of the procedure.

d) Extend the four wire ends (two connected to the battery terminals, two connected to where the original battery terminal wires intertied with the PCB) by soldering on additional wires. Make the wire extensions long enough to be extended approximately 6 cm outside the SL's enclosure. Be sure to cover the wire solder connections with heat shrink.

NOTE When working with the extension wires, be sure to keep the battery positive and negative extensions separate when bare to avoid electrical shock.

e) Close the SL such that the wires can extend outside the SL's enclosure without being pinched.

f) Some products are designed with openings in their enclosures such that the wires can fit through these openings without physically changing the SL's enclosure.

g) Some products do not have openings for wire extensions to fit through, in which case a hole must be drilled into the side of the SL's enclosure. A drill bit with a diameter slightly greater than the combined diameter of all four extension wires should be used. Choose a location on the SL's enclosure to minimize the extension wire length and minimize changes to the SL's enclosure. Be sure that the extension wires do not interfere with the SL's light output.

h) To ensure the SL still works after it has been rewired, connect the wire pairs (with connectors or electrical tape) so the original, unaltered circuit is replicated and turn the SL on. If the SL does not turn on, check that the wires are connected correctly and that the solder joints connecting wires are good.

6. PV MODULE CHARACTERISTICS TEST

6.1 Background

The purpose of the photovoltaic (PV) module I-V characteristics test is to validate the SL manufacturer's PV module data (if available) and determine the PV module's I-V characteristic curve under standard test conditions (STC).

Solar LED lamp units are often powered by PV modules having a power range from approximately 0.3 watts-peak (Wp) to 5 Wp. When selecting a measurement instrument, it is important to ensure that it is able to make accurate measurements of modules in the desired size range. The PV module can be measured with a solar simulator in accordance with IS 12762(Part 1). .

6.2 Test Outcomes

The test outcomes of the outdoor PV module I-V characteristics test are listed in Table 2.

Table 2. PV module I-V characteristics test outcomes
(*Clause* 6.2)

Sl. No (1).	Metric (2)	Reporting units (3)	Notes (4)
i)	Short-circuit current (I_{sc}) at STC	Amperes (A)	Report at STC
ii)	Open-circuit voltage (V_{oc}) at STC	Volts (V)	Report at STC
iii)	Maximum power point power (P_{mpp}) at STC	Watts-peak (W_p)	Report at STC
iv)	Maximum power point current (I_{mpp}) at STC	Amperes (A)	Report at STC
v)	Maximum power point voltage (V_{mpp}) at STC	Volts (V)	Report at STC
vi)	P_{load} Power at defined load	Watts	Report at STC
vii)	STC I-V Curve dataset	Volts (V), Amperes (A)	Delimited dataset

6.3 Procedure

6.3.1 *Equipment*

Sun simulator

6.3.2 *Method*

Measure the STC performance of the PV module by using the indoor sun simulator. In case of crystalline Si module the STC performance should be measured after initial exposure of the module. Transfer the STC performance and I-V curve of the PV module to NOCT.

Use IS 12762 (Part 1) for STC performance measurement.

7. BATTERY TEST

7.1 Background

The battery test is used to determine a SL's actual battery capacity and storage efficiency. This information is useful to determine if a battery is mislabelled or damaged. During the test the battery is connected to a battery analyser, which performs charge-discharge cycles on the battery. The last charge-discharge cycle data from the battery test is analysed to determine the actual battery capacity and battery storage efficiency.

7.2 Test Outcomes

The test outcomes of the battery test are listed in Table 3.

Table 3 Battery test outcomes
(*Clause* 7.2)

Sl. No. (1)	Metric (2)	Reporting units (3)	Note (4)
i)	Battery capacity (C_b)	Milliampere-hours (mAh) at a discharge current (0,x I_t A)	--
ii)	Battery storage efficiency (η_b)	Percentage (%)	At least two complete charge-discharge cycles are required for the calculation

7.3 Procedure

7.3.1 *Sealed Lead-Acid Battery Test*

The SL's sealed lead-acid battery is cycled on a battery analyser and the data from the final charge-discharge cycle is used to determine the SL's actual battery capacity and storage efficiency.

7.3.1.1 *Equipment requirements*

a) Battery analyser with the voltage, current, and capacity measurement tolerances specified in section 4 of IS 16048(Part 1)

7.3.1.2 *Test prerequisites*

The battery can be taken out of the lighting product for this test.

7.3.1.3 *Procedure*

a) Prime the battery using a charge rate of $0.1I_t$ A, a discharge rate of 0.1 I_t A, and the information in the battery cycling recommended practices given in annex B.

b) Using the battery analyser, continuously cycle the battery until the maximum battery capacity is reached (i.e., until the capacity improvement is less than or equal to 5 % over the previous battery capacity).

c) Ensure the battery is charged using a charge rate of $0.1I_t$ A and the information in the battery cycling recommended practices **(Annexure B**). After charging, the battery shall be stored in an ambient temperature of 20 °C ± 5 °C for not less than 1 h and not more than 4 h.

d) The battery shall be discharged at a rate of $0.1I_t$ A, using the information in the battery cycling recommended practices given in **Annexure B**, and the battery capacity shall be measured.

e) Continue cycling the battery until the change in measured battery capacity between subsequent cycles is less than or equal to 15 %, ensuring that the last two charge-discharge cycles have identical charge and discharge rates.

f) If the battery will be stored after undergoing this test, charge the battery using a charge rate of 0.1 I_t A and the information in the battery cycling recommended practices annex B.

7.3.1.4 *Calculations*

a) Determine the total energy input into the SL's battery during the final charge cycle (E_c) using the following formula:

$$E_c = \sum(V_c \times I_c \times \Delta t)$$

where

E_c is the energy entering the battery during the charge cycle, in watt-hours (Wh);

V_c is the voltage recorded during the charge cycle, in volts (V);

I_c is the current recorded during the charge cycle, in amperes (mA);

Δt is the time interval between subsequent data points, in hours (h).

b) Determine the total energy output from the SL's battery during the final discharge cycle using the following formula:

$$E_d = \sum(V_d \times I_d \times \Delta t)$$

where

E_d is the battery's energy output during the discharge cycle, in watt-hours (Wh);

V_d is the voltage recorded during the discharge cycle, in volts (V);

I_d is the current recorded during the discharge cycle, in amperes (mA);

Δt is the time interval between subsequent data points, in hours (h).

c) Determine the SL's battery capacity with data from the final discharge cycle using the following formula:

$$C_b = \sum(I_d \times \Delta t)$$

where

C_b is the measured battery capacity, in milliampere-hours (mAh);

I_d is the current recorded during the discharge cycle, in amperes (mA);

Δt is the time interval between subsequent current data, in hours (h).

d) Determine the SL's battery efficiency using the following formula:

$$\eta_b = \frac{E_d}{E_c}$$

where

η_b is the battery storage efficiency;

E_d is the battery's energy output during the discharge cycle, in watt-hours (Wh);

E_c is the energy input to the battery during the charge cycle, in watt-hours (Wh).

7.3.2 Nickel-Metal Hydride Battery Test

The SL's nickel-metal hydride battery is cycled on a battery analyser and the data from the final charge-discharge cycle is used to determine the SL's actual battery capacity and battery storage efficiency.

7.3.2.1 *Equipment Requirements*

Battery analyser with the voltage, current, and capacity measurement tolerances specified in section 4 of IS 16048(Part 1).

7.3.2.2 *Test prerequisites*

The battery can be taken out of the lighting product for this test.

7.3.2.3 *Procedure*

a) Prime the battery using the charge-discharge rates specified in section 7.1 of IEC 16048 (Part 2) and the information in the battery cycling recommended practices (**Annexure B).**

b) Using the battery analyser, continuously cycle the battery until the maximum battery capacity is reached (i.e., until the capacity improvement is less than or equal to 5 % over the previous battery capacity).

c) Follow the discharge performance at 20 °C procedure in section 7.3.2 of IS 16048(Part 1), using the measured battery capacity from the previous charge-discharge cycle as the target capacity for the next charge-discharge cycle.

d) Continue cycling the battery until the change in measured battery capacity between subsequent cycles is less than or equal to 15 %, ensuring that the last two charge-discharge cycles have identical charge and discharge rates.

e) If the battery will be stored after undergoing this test, charge the battery using the charge rates specified in section 7.1 of IS 16048(Part 1) and the information in the battery cycling recommended practices annexure B

7.3.2.4 *Calculations*

Perform the same calculations listed in 8.3.1.4.

7.3.3 *Lithium Ion Battery Test*

The SL's lithium-ion battery is cycled on a battery analyser and the data from the final charge-discharge cycle is used to determine the SL's actual battery capacity and battery storage efficiency.

7.3.3.1 *Equipment requirements*

Battery analyser with the voltage, current, and capacity measurement tolerances specified in section 4 of IS 16047.

7.3.3.2 *Test prerequisites*

The battery can be taken out of the lighting product for this test, if desired.

7.3.3.3 *Procedure*

a) Follow the discharge performance at 20 °C procedure in section 7.3.1 of IS 16047, using the measured battery capacity from the previous charge-discharge cycle as the target capacity for the next charge-discharge cycle.

b) Continue cycling the battery until the change in measured battery capacity between subsequent cycles is less than or equal to 15 %, ensuring that the last two charge-discharge cycles have identical charge and discharge rates.

c) If the battery will be stored after undergoing this test, charge the battery using the charge rates specified in section 4 of IS 16048(Part 1).

7.3.3.4 *Calculations*

Perform the same calculations listed in 7.3.1.4.

7.3.4 *Lithium iron Phosphate Battery Test*

The SL's lithium iron phosphate battery is cycled on a battery analyser and the data from the final charge-discharge cycle is used to determine the SL's actual battery capacity and battery storage efficiency.

7.3.4.1 *Equipment requirements*

Battery analyser with the voltage, current, and capacity measurement tolerances specified in section 4 of IS 16047.

7.3.4.2 *Test prerequisites*

The battery can be taken out of the lighting product for this test.

7.3.4.3 *Procedure*

a) Follow the discharge performance at 20 °C procedure in section 7.3.1 of IS 16047, using the measured battery capacity from the previous charge-discharge cycle as the target capacity for the next charge-discharge cycle.

b) Continue cycling the battery until the change in measured battery capacity between subsequent cycles is less than or equal to 15 %, ensuring that the last two charge-discharge cycles have identical charge and discharge rates.

c) If the battery will be stored after undergoing this test, charge the battery using the charge rates specified in section 4 of IS 16048(Part 1) and the information in the battery cycling recommended practices (annexure B).

7.3.4.4 *Calculations*

Perform the same calculations listed in 7.3.1.4.

7.3.5 *Nickel-Cadmium Battery Test*

The SL's nickel-cadmium battery is cycled on a battery analyser and the data from the final charge-discharge cycle is used to determine the SL's actual battery capacity and battery storage efficiency.

7.3.5.1 *Equipment requirements*

Battery analyser with the voltage, current, and capacity measurement tolerances specified in section 4 of IS 16048(Part 1)

7.3.5.2 *Test prerequisites*

The battery can be taken out of the lighting product for this test.

7.3.5.3 *Procedure*

a) Prime the battery using the charge-discharge rates specified in section 7.1 of IS 16048 (Part 1)and the information in the battery cycling recommended practices (**Annexure B)**

b) Using the battery analyser, continuously cycle the battery until the maximum battery capacity is reached (i.e., until the capacity improvement is less than or equal to 5 % over the previous battery capacity).

c) Follow the discharge performance at 20 °C procedure in section 7.2.1 of IEC 61951-1, using the measured battery capacity from the previous charge-discharge cycle as the target capacity for the next charge-discharge cycle.

d) Continue cycling the battery until the change in measured battery capacity between subsequent cycles is less than or equal to 15 %, ensuring that the last two charge-discharge cycles have identical charge and discharge rates.

e) If the battery will be stored after undergoing this test, charge the battery using the charge rates specified in section 7.1 of IS 16048 (Part 1)and the information in the battery cycling recommended practices **(Annexure B**).

7.3.5.4 *Calculations*

Perform the same calculations listed in 7.3.1.4.

7.4 Reporting

a) Battery capacity (Ah) at a specific discharge current

b) Battery storage efficiency (%)

c) Deviation of the average result from the SL's rating for each aspect tested, if available (%)

8 COMMENTS. FULL-BATTERY RUN TIME/ AUTONOMY TEST

8.1 Background

The full-battery run time captures one of the key system-performance metrics from a user's perspective. It combines the relationship between battery capacity, circuit efficiency lighting system power consumption, capability of LED driver circuit to provide the constant output irrespective of battery voltage and under realistic operating conditions.

In general terms, the full-battery run time test involves operating hours of a SL with a fully charged battery until the battery is discharged to the permissible discharge level i.e. load cut of condition **while maintaining the light output well within the rated level**.

8.2 Test Outcomes

The test outcomes of the full-battery run time test are provided in the respective tables

8.3 Procedure

8.3.1 *Equipment Requirements*

a) Lux meter

b) Scale

c) A darkened room or cabinet with direct luminance measurement under fixed geometry

d) Data-logging voltage device

e) Data-logging current device (e.g. voltage data logger and current transducer)

f) DC Current and voltage meters

8.3.2 *Test Method*

This test is conducted in three steps.

8.3.2.1 *Measurement of the light output & light distribution of the SL (Step 1)*

a) Set the SL in the dark room and work out the centre point of the SL in the room

b) Draw the circles of 1, 2, 3, 4 and 5 feet diameters from the centre point of the SL and mark it.

c) Keep the SL at the centre point with the fully charged battery and switch it ON

d) After 1 hour of switching ON of the SL measure the light output in lux at four equally distributed points on the periphery of each circle by keeping the detector in horizontal and vertical position respectively

e) Record the data as in Table 4.

Table 4. Light output measurement at different distances from the SL and different points
(*Clause* 8.3.2.1)

Sl No. (1)	**Distance from the centre of SL** (2)	**Detector position** (3)	**Lux at Point 1** (4)	**Lux at Point 2** (5)	**Lux at Point 3** (6)	**Lux at Point 4** (7)	**Average Lux** (8)
i)	1feet	Horizontal					
		Vertical					
ii)	2 feet	Horizontal					
		Vertical					
iii)	3 feet	Horizontal					
		Vertical					
iv)	4 feet	Horizontal					
		Vertical					
v)	5 feet	Horizontal					
		Vertical					

f) The average light output should meet the requirements as specified and the variation in light output measured at 4 different points should not be more than 3%. If it passes proceed to step 2.

8.3.2.2. *Ensuring of the constant light output irrespective of the battery voltage (Step 2)*

a) Power the SL by using the DC power supply by setting it at the nominal battery voltage and connect the DC current meter and voltmeter to measure the LED driver input and output parameters.

b) Switch on the lantern and measure the battery input current ,input voltage, the LED driver output voltage and current at four different battery voltages ranging from load cut off voltage and the battery full charge condition voltage.

c) Record the data as in the table 5

Table-5 LED Driver efficacy and output parameters as a function of battery voltage

(Clause 8.3.2.2*)*

SlNo (1)	Battery Voltage (V) (2)	LED Driver input parameters (3)			LED Driver out output parameters (4)			LED driver Efficiency % (5)	Remarks (Variation in the output current/power as function of battery voltage) (6)
		Voltage (V)	Current (mA)	Power (W)	Voltage (V)	Current (mA)	Power (W)		
i)									
ii)									
iii)									
iv)									

d) The conversion efficiency of the LED driver should match the specified value.

e) The variation in output current and power as function of battery voltage should not be more than 3 %.

f) If the above two parameters at d & e do not meet the specified value, the system will be considered as fail at this stage.

g) If the system passes proceed to step 3.

8.3.2.3 *Measurement of the autonomy of the system/ full battery run time(Step 3)*

a) Set the SL in the dark room (the temperature of the dark room should be in the range 25 to 30 ° C) and make sure that the battery used in the SL is fully charged.

b) Switch on the SL and note down the time of switching on of the SL

c) Keep on monitoring the battery voltage

d) Switch off the system the moment battery voltage reaches the load cut off value (The load cut off is required to set at a value up to which the battery discharge is permissible for example in case of a 12 V lead acid battery the load cut off is around 11.4 V)

e) Work out the total ON duration of the SL in hours

f) The total ON duration of the SL should meet the specified autonomy of the SL

8.3.3 *Reporting*

a) System meets the light output requirement and light distribution as per specifications (Yes/No)

b) Power fed to the LED is independent of the battery voltage (Yes/No)

c) SL meets the autonomy requirement (Yes/No)

9 CHARGE CONTROLLER BEHAVIOUR TEST

9.1 Background

Deep discharge and overcharge protection is important for user safety and battery longevity. Charge controlling is most important for products with lead-acid, Li-ion, and LiFePO4 batteries. The charge controller behaviour test contains five methods to examine a SL's charge controller. Every SL must be tested with the active deep discharge method, where the SL is discharged until reaching its low voltage disconnect (LVD) voltage or appropriately exceeding its recommended deep discharge voltage threshold. Every SL must also be tested with the active overcharge protection method, where the SL is charged until reaching its over voltage protection (OVP) voltage or appropriately exceeding its recommended OVP voltage threshold. For SL with NiMH batteries that have no active deep discharge protection, the passive deep discharge protection method must be used, where the SL's long-term discharging battery voltage is examined for safety. For SLs with NiMH batteries that have no active overcharge protection, the passive overcharge protection method must be used, where the SL's long-term charging current is examined for safety.

Every SL must also be examined for self-consumption. It is possible that a SL's electronics may draw substantial amounts of energy from the SL's batteries while the SL is not in use. This self-consumption may lead to shorter run times or problems when storing the SL for long periods of time.

9.2 Test Outcomes

The test outcomes of the charge controller behaviour test are listed in Table 6

Table 6 Charge controller behaviour test outcomes
(Clause 9.2)

Sl. No. (1)	Metric (2)	Reporting Units (3)	Notes (4)
i)	Active deep discharge protection	Yes/no	--
ii)	Deep discharge protection voltage	Volts (V)	Measured only if the SL has active deep discharge protection
iii)	Active overcharge protection	Yes/no	--
iv)	Overcharge protection voltage	Volts (V)	Measured only if the SL has active overcharge protection
v)	Passive deep discharge protection	Yes/no	Measured only for NiMH batteries with no active deep discharge protection
vi)	Passive deep discharge protection battery voltage at 24 h	Volts per cell (V/cell)	Required only if tested for passive deep discharge protection
vii)	Passive overcharge protection	Yes/no	Measured only for NiMH batteries with no active overcharge protection
viii)	Passive overcharge protection continuous charging current	Milliamperes (mA)	Required only if tested for passive overcharge protection
ix)	30-day battery self-consumption fraction	Percentage (%)	Fraction of the battery's measured capacity that is self-discharged over 30 days

9.3 Procedure

9.3.1 *Active Deep Discharge Protection Test*

The SL is discharged until its battery voltage reaches the SL's LVD voltage or drops sufficiently below the specified deep discharge protection voltage threshold for the SL's battery chemistry.[1)]

9.3.1.1 *Equipment requirements*

a) DC power supply

b) Volt meter and/or multi-meter

c) Data-logging voltage measurement device (optional)

1) Recommended deep discharge protection voltage thresholds according to battery chemistry are: 1.87 V/cell ± 0.05 V/cell for lead-acid, 1.00 V/cell ± 0.05 V/cell for NiMH and NiCd, 3.00 V/cell ± 0.05 V/cell for Li-ion, and 2.00 V/cell ± 0.05 V/cell for $LiFePO_4$.

d) Data-logging light meter or data-logging current measurement device (e.g., voltage data logger with a current transducer) (optional)

9.3.1.2 *Procedure*

a) Set the SL in the location where its parameters are to be monitored and/or data-logged.

b) Turn on the SL to begin discharging the battery. Continuously monitor the battery terminal voltage and visual light output.[2]

c) If the SL automatically turns off, the voltage immediately before it turns off is the SL’s deep discharge protection voltage.

d) If the battery terminal voltage drops sufficiently below the specified deep discharge protection voltage threshold without the SL turning off, no active deep discharge protection is incorporated into the SL’s charge controller.[3]

9.3.2 *Active Overcharge Protection Test*

The SL is charged until its battery voltage reaches the SL’s OVP voltage or sufficiently exceeds the specified overcharge protection voltage threshold for the SL’s battery chemistry.[4]

9.3.2.1 *Equipment requirements*

a) DC power supply

b) Volt meter and/or multi-meter

c) Ammeter and/or multi-meter

d) Data-logging voltage measurement device (optional)

e) Data-logging light meter or data-logging current measurement device (e.g., voltage data logger with a current transducer) (optional)

9.3.2.2 *Test prerequisites*

The SL must be either fully discharged at the start of the test or discharged enough to accept at least 30 min of charging before reaching its overcharge protection voltage or sufficiently exceeds the specified overcharge protection voltage threshold.

9.3.2.3 *Procedure*

The SL is set in the location where its parameters can be monitored and/or data-logged. The SL is charged via the PV module socket from a DC power supply with a series rsistor in place as shown in figure 2.

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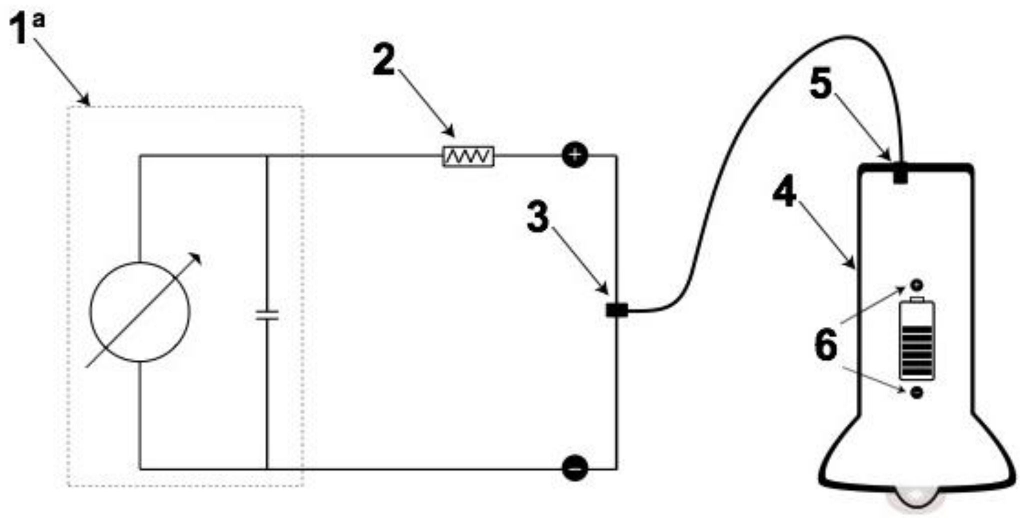
2) If using data-logging devices, the light does not need to be continuously visually monitored. The battery voltage and either the battery current or light output must be collected at intervals less than or equal to 1 min.

3) In some cases, the SL ’s charge controller will have a LVD voltage that is less than the specified deep discharge protection voltage threshold; therefore, the person conducting the test has the discretion to allow the battery voltage to proceed slightly below the specified deep discharge protection voltage threshold if deemed safe and necessary.

4) Recommended overcharge protection voltage thresholds according to battery chemistry are: 2.42 V/cell ± 0.05 V/cell for lead-acid, 1.40 V/cell ± 0.05 V/cell for NiMH and NiCd, 4.10 V/cell ± 0.05 V/cell for Li-ion, and 3.60 V/cell ± 0.05 V/cell for $LiFePO_4$.



Key
1 DC power supply
2 Series protection resistor
3 Plug
4 Solar lantern
5 PV module input socket
6 Battery
a Set current limiting with the maximum power point current at STC, I_{mpp}, from the PV module I-V characteristics

Figure 2 – Schematic of the DC power supply-SL connection using a series protection resistor

a) Adjust the current limiting value of the DC power supply to the PV module's maximum power point current at STC, I_{mpp}

b) Due to voltage drops from the PV module's blocking diode, cable losses, and the series resistor, set the power supply output voltage, V_{ps}, using the following formula:

$V_{ps} = 1.25 \times V_{b,max}$

where

V_{ps}	is the DC power supply output voltage, in volts (V);
$V_{b,max}$	is the SL's battery's maximum charge voltage, in volts (V), which can be obtained from the battery cycling recommended practices (Annexure C).

c) Connect the PV module socket of the SL to the DC power supply in series with a protection resistor.[5] The voltage drop in the series resistor should be between 10 % and 15 % of the voltage setting of the DC power supply (V_{ps}); therefore, size the resistor based on the following formula:

$$\frac{0.1\text{x } V_{ps}}{I_{mpp}} \le R_s \le \frac{0.15\text{x } V_{ps}}{I_{mpp}}$$

where

V_{ps}	is the DC power supply output voltage, in volts (V);
I_{mpp}	is the PV module's maximum power point current at STC, in amperes (A), obtained from the outdoor PV module I-V characteristics test
R_s	is the resistance of the series resistor, in ohms (Ω).

d) Ensure the series resistor's power dissipation rating is greater than or equal to the value given by the following formula:

$$P_{rs} = I_{mpp}^2 \times R_s$$

where

P_{rs}	is the series resistor's minimum required power dissipation, in watts (W);
I_{mpp}	is the PV module's maximum power point current at STC, in amperes (A), obtained from the outdoor PV module I-V characteristics test
R_s	is the resistance of the series resistor, in ohms (Ω).

e) Charge the SL at V_{ps} and I_{mpp} while continuously monitoring the battery voltage and current.[6]

f) If the SL automatically stops accepting charge, the voltage immediately before it turns off is the SL's overcharge protection voltage.

NOTE For some SL's, the current will not stop completely, but will begin tapering off when the SL's battery voltage reaches its overcharge protection voltages or slightly above the specified OVP voltage threshold if deemed safe and necessary. Never let the battery voltage exceed 4.25 V/cell for Li-ion batteries, otherwise there is a risk of explosion.

g) If the battery terminal voltage sufficiently exceeds the specified OVP voltage threshold while the continues charging, no active overcharge protection is incorporated into the SL's charge controller.[7]

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5) This protection resistor is only needed in cases where a "shunt regulator" is built in; however, as a schematic of the SL's electronics is usually not provided, this resistor should be used in all cases for safety reasons.

6) If using a data-logging device, the battery voltage and current input must be collected at intervals less than or equal to 1 min.

9.3.3 *Passive Deep Discharge Protection Test* **:** The SL is left to discharge for 24 h and the voltage after 24 h is recorded. This method is only performed on SLs with NiMH batteries that show no active deep discharge protection.

9.3.3.1 *Equipment requirements*

a) DC power supply

b) Volt meter and/or multi-meter

9.3.3.2 *Test prerequisites*

The SL must have undergone the active deep discharge protection test, such that its battery voltage has just passed 0.95 V/cell when discharging.

9.3.3.3 *Procedure*

a) Specify the accepted 24 h passive deep discharge battery protection voltage.[8)]

b) Turn on the SL and let it discharge for 24 h.

c) The battery voltage after 24 h is the SL's passive deep discharge battery protection voltage.

9.3.4 *Passive Overcharge Protection Test*

The SL's PV module's short circuit current alone may prove the SL has passive overcharge protection, otherwise the SL is overcharged and the charging current is observed to determine if the SL has passive overcharge protection. This method is only performed on SLs with NiMH batteries that show no active overcharge protection.

9.3.4.1 *Equipment requirements*

a) DC power supply

b) Current meter and/or multi-meter

c) Data-logging voltage measurement device (optional)

d) Data-logging current measurement device (e.g., voltage data logger with a current transducer) (optional)

9.3.4.2 *Test prerequisites*

The SL must have undergone the active deep discharge protection test, such that its battery voltage has just passed 1.45 V/cell when charging.

9.3.4.3 *Procedure*

a) Set the SL and charge via the PV module socket from a DC power supply.

b) Determine the accepted passive overcharge protection continuous battery charging current.[9)]

c) Compare the PV module's short-circuit current at STC (I_{SC}) to the passive overcharge protection continuous battery charging current. If I_{SC} is the smaller of

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[7)] In some cases, the SL's charge controller will have an OVP voltage that is greater than the specified OVP voltage threshold; therefore, the person conducting the test has the discretion to allow the battery voltage to proceed

[8)] A 24 h passive deep discharge battery protection voltage of greater than or equal to 0.08 V/cell is recommended for NiMH batteries.

[9)] A passive overcharge protection continuous battery charging current of less than or equal to twice $0.1 I_t$ A is recommended for NiMH batteries.

the two, the SL has passive overcharge protection and no further testing is necessary

d) Set the current limiting and voltage values of the DC power supply to the PV module’s new short-circuit current and open-circuit voltage, respectively.

e) Connect the DC power supply to the SL’s PV module input socket and entire PV cable and calculate the voltage drop, V_{drop}, between the power supply’s output and the SL’s battery terminals.[10]

f) Add V_{drop} to the battery end of charge voltage, V_{charge}, which is determined by multiplying the number of battery cells by the specified OVP voltage threshold for NiMH batteries from the active overcharge protection test. This is called the total charge voltage, V_{max}.

g) Plot a vertical line at V_{max} on the new I-V curve that extends from the voltage axis to the I-V curve.

h) Plot a horizontal line that intersects the new I-V curve at the same point V_{max} does and extends to the current axis. The current where the horizontal line intersects the current axis is the charging current.

j) If the charging current is less than or equal to twice $0{,}1I_t$ A, the SL has passive overcharge protection.

9.3.5 *Standby Self-Consumption Measurement (Idle Current)*

This measurement quantifies the self-consumption of a SL when not in use. If the self-consumption is substantial, it may affect the use of the SL.

9.3.5.1 *Equipment requirements*

Ammeter with a precision of 0.01 mA (data-logging functionality is optional)

9.3.5.2 *Test prerequisites*

The SL’s battery should be discharged to its LVD or, in the case of the SL is not having a LVD, the specified deep discharge protection voltage threshold.

9.3.5.3 *Procedure*

a) Break the SL’s circuit at the battery’s negative terminal, connect the current meter in series, and ensure the SL is turned off.

b) Wait 5 min to allow the SL to stabilize. Then, over a 10 min period, record (or data-log) the current draw at the battery’s negative terminal at intervals less than or equal to 1 min.

9.3.5.4 *Calculations*

a) Determine the fraction of capacity the battery self-consumes over a 30-day period using the following formula:

$$F_{\mathrm{b,self}} = \frac{I_{\mathrm{avg,self}} \times (720\ \mathrm{h}/30\ \mathrm{days})}{C_{\mathrm{b}}}$$

where

[10] If the SL is having an integrated PV module, connect the DC power supply to the ends of the internal leads where the PV module connects to the SL’s circuitry.

$F_{b,self}$ is the fraction of capacity the battery self-discharges over 30 days (%);

$I_{avg,self}$ is the average battery current draw over the 10 min data-collection period, in milliamperes (mA);

C_b is the measured battery capacity, in milliampere-hours (mAh), obtained from the battery test .

10. SOLAR CHARGE EFFICIENCY TEST

10.1 Back ground

The solar charge test provides estimates for two key sources of energy loss during solar charging: suboptimal operation of the solar module ("solar operation efficiency") and losses from the SL's internal electronic circuits that charge the battery ("generator-to-battery efficiency"). Along with the battery charge efficiency , these values are used in the solar run time calculation.

A power supply along with two resistors is used to simulate a solar module and charge a SL's battery. The voltage operating point during the test combined with the solar I-V curve is used to calculate the solar operating efficiency. Measurements of energy input to the SL solar charging port and SL battery are used to estimate the generator-to-battery efficiency.

If the SL is a kit that has multiple batteries that can be charged simultaneously by a single solar module, the test should be done with all the batteries connected at once. This will require additional measurements of battery current and voltage for each battery.

10.2 Test Outcomes

The test outcomes of the solar charge test are listed in Table 7.

Table 7 Solar charge efficiency test outcome

(Clause 10.2*)*

Sl. No. (1)	Metric (2)	Reporting units (3)	Note (4)
i)	Solar operation efficiency ($\eta_{sol\text{-}op}$)	Percentage	This is representative of the efficiency with respect to optimal operation of the PV module (where optimal operation is at the maximum power point).
ii)	Generator-to-battery charging efficiency ($\eta_{g\text{-}b}$)	Percentage	This is a lump figure for the whole lighting kit and is not disaggregated by lighting unit.
iii)	Solar run time (standard solar day)	Hours (h)	Multiple outcomes will be found—one for each setting on each independent lighting unit.
iv)	Solar charging system characteristics	n/a	This describes key features of the solar charging circuit

10.3 Procedure

10.3.1 *Solar Charge EfficiencyTest*

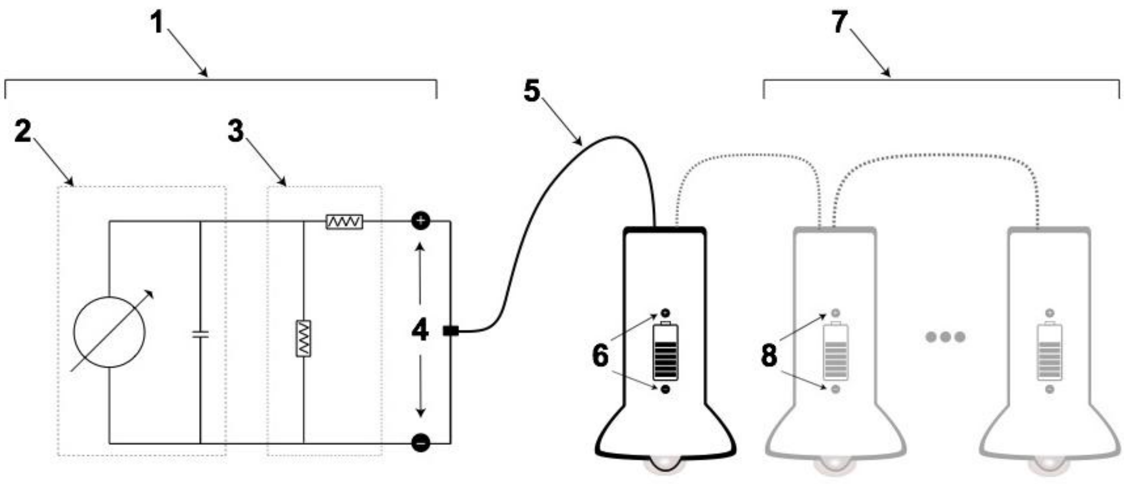
The current and voltage from an electronics setup that simulates a solar module and into the SL battery are recorded at one minute intervals after the test setup is left to stabilize for 5 min.

10.3.1.1 *Equipment requirements*

a) Programmable power supply with constant-voltage and constant-current modes and ability to automatically step through a timed programme

b) Data-logging voltage devices

c) Data-logging current devices (e.g. voltage data logger and current transducer



1 PV simulation circuit
2 Laboratory power supply
3 Series and parallel resistors (or variable resistors)
4 PV simulation circuit output (measure current and voltage here during simulated charging)
5 Connection cable from PV simulation circuit to lighting unit
6 SL's battery (measure current and voltage here during simulated charging)
7 [optional] Additional lighting units with separate batteries that are included in the kit
8 [optional] Additional lighting unit battery(-ies) (measure current and voltage here during simulated charging)

Figure 3 Schematic of the power supply and SL connection for the solar charge efficiency measurement

10.3.1.2 *Procedure*

Preparation for the test:

a) Use the NOCT transferred I-V curve to find appropriate resistor values and power supply set points to simulate the PV module operating at NOCT during the charging cycle. Using a computer spread sheet is required for this step.

1) Use the spread sheet to estimate the response curve of the PV simulator circuit over the range of voltages that corresponds to the I-V curve.

2) The input variables to the spread sheet should be the following:

i. Series resistance

ii. Parallel resistance

iii. Voltage set point

iv. Current set points corresponding to each level of simulated solar radiation listed in Table 8

3) The circuit simulation should be based on Ohm's law.

4) The spread sheet should estimate the NOCT current at evenly spaced voltage points by linearly interpolating between points on the measured I-V curve.

5) Create a scaled I-V curve for each level of simulated solar radiation listed in table 8 by multiplying the interpolated current values by the ratio of the desired solar radiation level to 1 000 W/m^2:

$$I_{\mathrm{pv},i,j} = I_{\mathrm{interp},j} \times \frac{G_i}{1\ 000\ \mathrm{W/m^2}}$$

where

$I_{\mathrm{pv},i,j}$ is the scaled, interpolated current at each solar radiation level i and voltage point j, in amperes (A);

$I_{\mathrm{interp},j}$ is the interpolated current at NOCT and 1 000 W/m^2 at each voltage point j, in amperes (A);

G_i is the simulated solar radiation, in watts per square meter (W/m^2);

6) Use a non-linear minimization technique to minimize the weighted sum of the squared residuals between the scaled, interpolated NOCT I-V curve values and the simulated I-V curve of the PV simulator by altering the input variables. To give preference for close agreement near the maximum power point, the SSR at each point should be weighted by the product of the duration of each solar radiation step (from Table R.2) and the power in the scaled NOCT curve:

$$\text{weighted SSR} = \sum_i \left(t_i \times \sum_j I_{\mathrm{pv},i}(V_j) \times V \times \left(I_{\mathrm{fit},i}(V_j) - I_{\mathrm{pv},i}(V_j)\right)^2 \right)$$

Where

t_i is the duration of time at each solar radiation level *i*, in hours (h);

V_j is the voltage at each current and voltage point *j*, in volts (V);

$I_{\mathrm{pv},i}(V_j)$ is the scaled, interpolated current at each solar radiation level *i* and voltage point *j*, in amperes (A);

$I_{\mathrm{fit},i}(V_j)$ is the fitted simulated current at solar radiation level *i* and voltage *j*, in amperes (A);

7) The outcomes of the spreadsheet are the best fit input variables:

i) Series resistance (R_S)

ii) Parallel resistance (R_P)

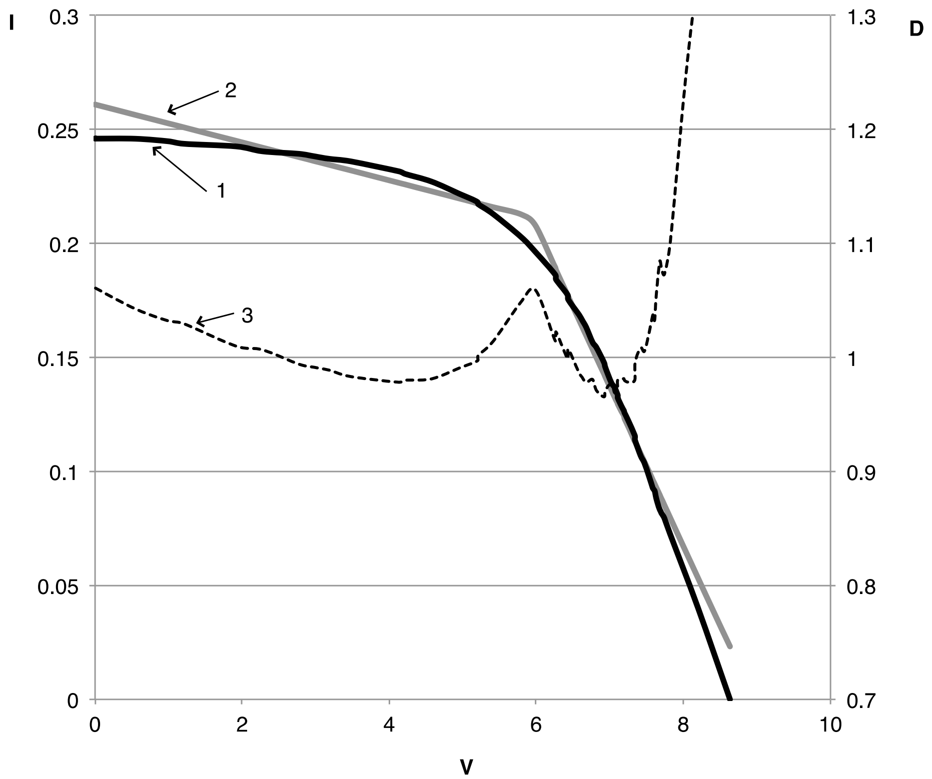
iii) Voltage setpoint (V_{sim})

iv) Current setpoints ($I_{sim,1000}$, $I_{sim,900}$, $I_{sim,700}$, $I_{sim,500}$, $I_{sim,300}$)

b. Build a PV simulator circuit like the one pictured in Figure 3 using fixed or variable resistors with an appropriate power rating wired in parallel and series with the power supply.

c. Measure the actual values of the parallel and series resistance in the PV simulator circuit and input them in the spreadsheet from step (a). Re-solve the minimization problem with those resistances held constant to find new ideal values for the other input variables.

d. Check that the simulated I-V curve is a reasonable approximation of the true curve by calculating the deviation ratio between the simulated and scaled, interpolated NOCT I-V curves. The deviation ratio is defined as the simulated current divided by the scaled, interpolated NOCT current at each voltage point. For this calculation, use the true values of the input variables rounded to the precision of the test equipment. In the example below, the deviation ratio is close to unity (between 0,95 and 1,05, or less than 5 % error) in the key parts of the I-V curve (at and to the left of the maximum power point).



Key

I is current with units of amperes on the primary vertical axis
V is voltage with units of volts on the horizontal axis
D is the deviation ratio (unitless) on the secondary vertical axis

1 is the measured "true" I-V curve, plotted against the primary axis
2 is the I-V curve from the PV simulator, plotted against the primary axis
3 is the deviation ratio as a function of voltage, plotted on the secondary axis

Figure 4 – Example "true" and simulated I-V curves plotted with the deviation ratio

e) Optionally, experimentally verify the calculated deviation for the 1 000 W/m^2 I-V curve:

1) Connect data logging current and voltage sensors to the PV simulator output. Set the sensors to log data at very short intervals, 1 s or less.

2) Simulate a PV module at NOCT and 1 000 W/m^2. Set the power supply current and voltage set points to $I_{sim,1000}$ and V_{sim}.

3) Measure an I-V curve for the PV simulator. Connect a variable resistor between the positive and negative terminals of the PV simulator and slowly sweep from high to low resistance and back.

4) Disconnect the resistor and stop the data collection.

5) Check to ensure the quality of the I-V curve data; cross check with the original (target) I-V curve to ensure the PV simulator is reasonably close, particularly in the region with voltages slightly below the maximum power point. The figure below shows an example comparison. The true I-V curve (line 1) is compared to the simulated I-V curve (line 2). The deviation ratio between the two curves is defined as the simulated current divided by the true current at each voltage point.

Charging the SL using the PV simulator:

f) Set up the prepared SL and PV simulator circuit with current and voltage sensors. Set the data logging at 1 minute or more frequent intervals.

i) Current entering the SL's battery(s), in amperes (A).

ii) Voltage across the SL's battery(s), in volts (V).

iii) Current provided by the PV simulator circuit, in amperes (A).

iv) Voltage across the PV simulator circuit output, in volts (V).

g) Programme the power supply to simulate a "standard solar day" of charging using the steps indicated below (Table 8). It is acceptable to insert short pauses at 0 volts between steps to facilitate identification of solar radiation levels during data analysis.

Table 8 Simulated solar day power supply settings
(*Clause* 10.3.1.2)

Sl. No. (1)	**Step duration (2)**	**Simulated solar radiation (3)**	**Current set point (4)**	**Voltage set point (5)**
i)	0.5 h	300 W/m^2	$I_{sim,300}$	V_{sim}
ii)	0.5 h	500 W/m^2	$I_{sim,500}$	V_{sim}
iii)	1 h	700 W/m^2	$I_{sim,700}$	V_{sim}

iv)	1 h	900 W/m^2	$I_{sim,900}$	V_{sim}
v)	1 h	1000 W/m^2	$I_{sim,1000}$	V_{sim}
vi)	1 h	900 W/m^2	$I_{sim,900}$	V_{sim}
vii)	1 h	700 W/m^2	$I_{sim,700}$	V_{sim}
viii)	0.5 h	500 W/m^2	$I_{sim,500}$	V_{sim}
ix)	0.5 h	300 W/m^2	$I_{sim,300}$	V_{sim}

h) Check the connections and set points, then begin data logging and start the simulated charging cycle. After the 7 h charging cycle is complete, stop the power supply, stop the data logging, disconnect the product from the PV simulator, and ensure the current and voltage data are valid with a quick check.

10.3.1.3 *Calculations*

a) Determine the energy supplied by the PV simulator circuit ($E_{pvsim,o}$) using the following formula:

$$E_{pvsim,o} = \sum_j \left(I_{pvsim,j} \times V_{pvsim,j} \times t_j \right)$$

where

$E_{pvsim,o}$ is the energy supplied by the power supply, in watt-hours (Wh);

$I_{pvsim,j}$ is the current supplied by the power supply, in amperes (A);

$V_{pvsim,j}$ is the voltage supplied by the power supply, in volts (V);

t_j is the duration of time associated with each current and voltage point *i*, in hours (h).

b) Determine the energy entering each battery ($E_{b,i}$) using the following formula:

$$E_{b,i} = \sum_j \left(I_{b,i,j} \times V_{b,i,j} \times t_j \right)$$

where

$E_{b,i}$ is the energy entering battery *i*, in watt-hours (Wh);

$I_{b,i,j}$ is the current entering battery *i* at time *j*, in amperes (A);

$V_{b,i,j}$ is the voltage entering battery *i* at time *j*, in volts (V);

t_j is the duration of time associated with each current and voltage point *j*, in hours (h).

c) Determine the energy allocation ratio for each battery using the following formula:

$$\alpha_i = \frac{E_{b,i}}{\sum_i E_{b,i}}$$

where

α_i is the energy allocation ratio for battery *i*, a unitless ratio;

$E_{b,i}$ is the energy entering battery *i*, in watt-hours (Wh);

d) Determine the generator-to-battery charging circuit efficiency ($\eta_{g\text{-}b}$) using the following formula:

$$\eta_{g\text{-}b} = \frac{\sum E_{b,i}}{E_{pvsim}}$$

where

$\eta_{g\text{-}b}$ is the generator-to-battery charging circuit efficiency;

$E_{b,i}$ is the energy entering the battery, in watt-hours (Wh);

E_{pvsim} is the energy supplied by the power supply, in watt-hours (Wh).

e) Determine the deviation ratio as a function of voltage for each simulated I-V curve. For this calculation, use the spreadsheet from step (a) with the actual values of the input variables that were used during the test.

$$D_i\left(V_j\right) = \frac{I_{fit,i}\left(V_j\right)}{I_{pv,i}\left(V_j\right)}$$

where

$D_i(V_j)$ is the deviation ratio at each simulated solar radiation level i and voltage point j (unitless);

$I_{fit,i}(V_j)$ is the simulated current for simulated solar radiation level i and voltage point j, in amperes (A);

$I_{pv,i}(V_j)$ is the true current at each point from the scaled, interpolated I-V curve for simulated solar radiation level i and voltage point j, in amperes (A).

f) Modify the current data by the deviation ratio to correct for deviation from optimal operation caused by the simulated PV circuit's lack of fit with the true I-V curve. Use interpolation to estimate the deviation ratio at each voltage operating point i using linear interpolation between adjacent deviation ratios from the series that was calculated in the previous step. The modified current values calculated below can be described as the "current that would have been produced if a PV module were operated at the same point relative to the true I-V curve as was observed relative to the simulated I-V curve."

$$I_{\text{pvsim,mod},j} = \frac{I_{\text{pvsim},j}}{D_i\left(V_j\right)}$$

where

$I_{\text{pvsim,mod},j}$ is the modified current at each point in the simulated solar charging day, in amperes (A);

$I_{\text{pvsim},j}$ is the measured current at each point in the simulated solar charging day, in amperes (A);

$D_i(V_j)$ is the deviation ratio at each point in the solar charging day, which depends on the operating voltage and the simulated solar radiation level (unitless).

g) Estimate the modified energy for the simulated solar charging day

$$E_{\text{pvsim,mod}} = \sum_j \left(I_{\text{pvsim,mod},j} \times V_{\text{pvsim},j} \times t_j\right)$$

where

$E_{\text{pvsim,mod}}$ is the modified energy supplied by the PV simulator, in watt-hours (Wh);

$I_{\text{pvsim,mod,i}}$ is the modified current supplied by the PV simulator, in amperes (A);

$V_{\text{pvsim,i}}$ is the voltage supplied by the PV simulator, in volts (V);

t_{i} is the duration of time associated with each current and voltage point i, in hours (h).

h) Estimate the solar operation efficiency ($\eta_{\text{sol-op}}$).

$$\eta_{\text{sol-op}} = \frac{E_{\text{pvsim,mod}}}{G \times P_{\text{pv,NOCT}}}$$

where

$\eta_{\text{sol-op}}$ is the solar operation efficiency (unitless);

$E_{\text{pvsim,mod}}$ is the modified energy supplied by the PV simulator, in watt-hours (Wh);

G *is the solar resource(typically 5) in kilowatt-hours per square meter (kWh/m^2) or* equivalent *full-sun hours (h);*

$P_{\text{pv,NOCT}}$ *is* the *maximum power point of the PV module at NOCT and 1000 W/m^2 in watts (W).*

i) Estimate the solar run time on each setting for each battery with the equation below:

$$t_{\text{SRT,s},i} = \min\left(\frac{G_{\text{solar}} \times P_{\text{mpp,NOCT}} \times \eta_{\text{sol-op}} \times \alpha_i \times \eta_{\text{g-b}} \times \eta_{\text{batt}}}{P_{\text{FBR,s},i}}, t_{\text{FBR,s},i}\right)$$

where

$t_{\text{SRT,s},i}$ is the solar run time on setting “s” for battery *i* in hours (h);

G_{solar} is the total solar resource in kWh/m^2 (or “full sun hours”) – typically use the standard solar day, 5 kWh/m^2;

$P_{\text{mpp,NOCT}}$ is the maximum power point of the PV module at NOCT in watts (W);

$\eta_{\text{sol-op}}$ is the solar operating efficiency as a fraction;

$\eta_{\text{g-b}}$ is the generator-to-battery circuit efficiency as a fraction;

η_{batt} is the battery efficiency as a fraction;

$P_{\text{FBR,s},i}$ is the average power during the full-battery run time test on setting “s” for battery *i* in watts (W);

$t_{\text{FBR,s},i}$ is the full-battery run time on setting “s” for battery *i* in hours (h).

j) (optional step) Repeat previous step with an alternative solar resource

k) Based on the test data, identify if the following characteristics are present in the circuit between the solar module and the battery:

1) DC-DC converter (check to see if the current is different)

2) Constant current with voltage drop (use the relationship between current and voltage drop to approximate the resistance of the circuit)

11. DUTY CYCLE TEST

11.1Background

The duty cycle test is the very important test which provides the estimations whether the SL can meet the defined daily operating hours requirement with the PV module attached with it when exposed to the specified daily sun. The daily operating hours of the SL with the attached PV module PV module are defined in the specifications of the SL.

11.2 Test Outcomes

The test outcome is the estimation the Ah pumped inside the battery corresponding to the Ah discharged from the battery required for daily operation of the SL as specified.

11.3 Procedure

11.3.1 *Duty Cycle Test*

Measurement of the total Ah discharged from the battery required for specified daily operation and the Ah pumped inside the battery corresponding to the total Ah discharged

11.3.1.1 *Equipment required*

a) Programmable power supply with constant-voltage and constant-current modes and ability to automatically step through a timed programme

b) Data-logging voltage devices

c) Data-logging current devices (e.g. voltage data logger and current transducer

d) Stop watch

11.3.1.2*Procedure*

a) Fully charge the battery of the SL as defined in the battery test section

b) Connect the data logging devices to monitor the battery terminal voltage and the battery discharge current

c) Switch ON the lantern and note down the time of switching ON of the SL and monitor the discharge current from the battery

d) Keep the SL ON for the daily specified hours and work out the total discharged current (I_{load})from the battery

e) Calculate the corresponding Ah required to be pumped inside the battery (I_{bin}) for discharging I_{load} from the battery (For example if the battery charge - discharge efficiency is 90% divide I_{load} by .9. It will give the I_{bin})

f) Connect the attached PV module for charging the SL and monitor the instantaneous and integrated radiation on the module surface and the battery charging current. For an integrated irradiance (as specified for the SL under test to meet the specified hours of operation) work out the total charging current pumped inside the battery (I_{charge})

g) Note down I_{charge} and I_{bin}

h) Repeat the test for four cycles

11.4 Pass Criterion:

The I_{charge} needs to be equal or more than I_{bin}

11.5 Reporting

SL pass the duty cycle Yes/No

12. TEMPERATURE COMPENSATION

12.1 Background:

Depending on the battery chemistry the recommended over charge protection voltages (OPV) is defined at a particular temperature where as in real sense the temperature at which the S L is charged keeps varying through- out the year. Hence in order to ensure proper charging of the battery irrespective of the temperature it is required to have the temperature compensation arrangement in the SL electronics

12.2 Test out comes

The OPV incorporated in the circuit measured in the entire temperature range of operation of the SL is required to match the OPV threshold voltage of the battery specified at that temperature

12.3 Procedure

12.3.1 *Temperature Compensation Test*

Measure the OPV while keeping the SL at different temperatures in its realistic operating temperature range

12.3.1.1 *Equipment required*

a) Programmable DC power supply
b) Volt meter and/or multi-meter
c) Heating and cooling chamber

12.3.1.2 *Procedure*

a) Install the SL inside the heating and cooling chamber and take the battery terminal access out side the chamber.

b) Set the chamber temperature at 27 C and measure the OPV as in **Test 9**. The OPV should not exceed the value as defined for the battery technology used in the SL

c) Increase the temperature of the chamber to the maximum operating temperature of the SL for which it has been designed. Wait for 30 minutes and measure the OPV.

d) Now decrease the temperature of the chamber to the lowest operating temperature of the SL for which it is designed and measure the OPV

e) Note down the OPV values measured at all the three temperatures

12.4 Pass Criterion

The OPV measured at all the three temperatures should match the recommended OPV values of the battery of the SL under test for the same temperature

12.5 Reporting

Appropriate temperature compensation incorporated in the system (Yes/No)

13 OTHER PROTECTION TEST

In addition the battery charging and discharging protection for reliable operation of the SL, it is required to have the protection for the various mishaps/accidents.

13.1 Equipment Required

DC Power supply, Voltmeter and current meter

13.1.1 *No Load Protection*

13.1.1.1 *Purpose*
The purpose is to test that the SL can withstand the accidental open circuiting of the load when it is ON.

13.1.1.2 *Procedure*
Switch ON the SL and take out the load from the LED driver terminals .Keep the system in this position for 30 minutes. Again connect the Load.

13.1.1.3 *Requirement*
The requirement is that the SL should work normally after this conditioning

13.1.2 *Load Short Circuit Protection*

13.1.2.1 *Purpose*
The purpose is to test that the SL can withstand the accidental short circuiting of the load when it is ON

13.1.2.2 *Procedure*
Switch ON the SL and take out the load from the LED driver terminals .Short circuit all the terminals of the LED driver for 30 minutes. After 30 minutes again connect the Load.

13.1.2.3 *Requirement*
The requirement is that the SL should work normally after this conditioning

13.1.3 *Battery Reverse Polarity Protection*

13.1.3.1 *Purpose*
The purpose is to test whether the SL can withstand the wrong connection of the battery made by mistake

13.1.3.2 *Procedure*

a) Connect the PV module to the SL and start charging the battery.
b) Once the charging process is started interchange the battery terminals and keep the SL in this condition for 30 minutes.
c) After 30 minutes disconnect the PV module make the connections proper and check whether any fuse is blown off or not. In case the fuse is blown off place the fuse .

13.1.3.3 *Requirement*
The requirement is that the system should charge properly after this conditioning

13.1.4 *LED driver Reverse Polarity Protection*

13.1.4.1 *Purpose*
The purpose is to test whether the SL can withstand the wrong connection of the LED driver made by mistake.

13.1.4.2 *Procedure*

a) Connect the power supply to power the LED driver by setting the voltage equal to nominal battery voltage and make sure the Load is ON
b) Once the SL is ON , interchange the input terminals of the LED driver and keep the SL in this condition for 30 minutes
c) After 30 minutes make the connections proper.

13.1.4.3 *Requirement*

The requirement is that the SL should function properly after this conditioning

13.2 Reporting

a) Load short circuit protection provided Yes/NO
b) No Load protection provide Yes/No
c) Battery reverse polarity protection Provided Yes/ NO
d) LED driver reverse polarity protection provided Yes/NO

14 MECHANICAL DURABILITY TEST

14.1 Background

The mechanical durability test captures a SL's robustness in withstanding the rigors of expected daily usage. The mechanical durability test includes the drop test & the switch and connector test.

During the drop test, the SL is dropped from a height of 1 m onto a concrete surface. Six drops occur per SL sample, with each drop impacting a different side of the sample. During the switch and connector test, each switch and/or connector of the SL samples SL sample is cycled 1000 times.

Throughout these tests, the SL sample is examined for functionality, damage, and the presence of user safety hazards.

14.2 Test Outcomes

The test outcomes of the mechanical durability test are listed in Table9

Table 9– Mechanical durability test outcomes
(Clause 14.2)

Sl. No. (1)	**Metric** **(2)**	**Reporting units** **(3)**	**Notes** **(4)**
i)	Drop test sample functionality	Yes/no	--
ii)	Drop test user safety hazard(s) present	Yes/no, description	--
iii)	Drop test sample damage	Yes/no, description	--

iv)	Switch and connector test cycles achieved	Cycles	--
v)	Switch and connector test sample functionality	Yes/no	--
vi)	Switch and connector test user safety hazard(s) present	Yes/no, description	--
vii)	Switch and connector test sample damage	Yes/no, description	--

14.3 Procedures

14.3.1 *Drop Test*

The SL sample is dropped on six different sides from a height of 1 m onto a level concrete surface and examined for functionality, user safety hazards, and damage.

14.3.1.1 *Equipment requirements*

a) Tape measure or ruler at least 1 m in length

b) Camera

14.3.1.2 *Test prerequisites*

At the start of the drop test the SL samples should be minimally altered (ideally unaltered), fully functional, and have sufficient charge to check for functionality throughout the test.

If the SL samples have multiple units or components, determine an appropriate order to test the parts need to undergo the drop test. SL samples or sample parts that are intended to be stationary (e.g., separate control boxes, lamp units intended to be mounted, etc.) and PV modules do not need to be drop-tested. Portable SL samples or sample parts (e.g., torches, lanterns, desktop lamps, etc.) should be drop tested.

NOTE This test is destructive test. In case the SL fails this test one more identical sample may be asked from the manufacturer at this stage and in case the other sample also fails this test the sample will be considered fail.

14.3.1.3 *Apparatus*

Choose an appropriate location to perform the drop test. The location should have a smooth, level concrete surface with ample space to avoid personal injury from a SL projectile (e.g., glass and/or plastic shards). A height of 1 m must be established from the ground to begin the drop.

14.3.1.4 *Procedure*

1)Drop the SL sample six times from a height of 1 m—once on each of the six “faces” of the product, taking care to drop the SL sample on parts deemed mechanically weak (e.g., handles, loose parts, etc.).

NOTE Each time the product should impact the concrete on a different face: the SL sample is rotated by 90° along the x-axis following each of the first three drops, rotated by 90° along the y-axis from its initial drop orientation for the fifth drop, and rotated 180° along the y-axis from its fifth drop orientation for the sixth drop (see Figure W.1 below).

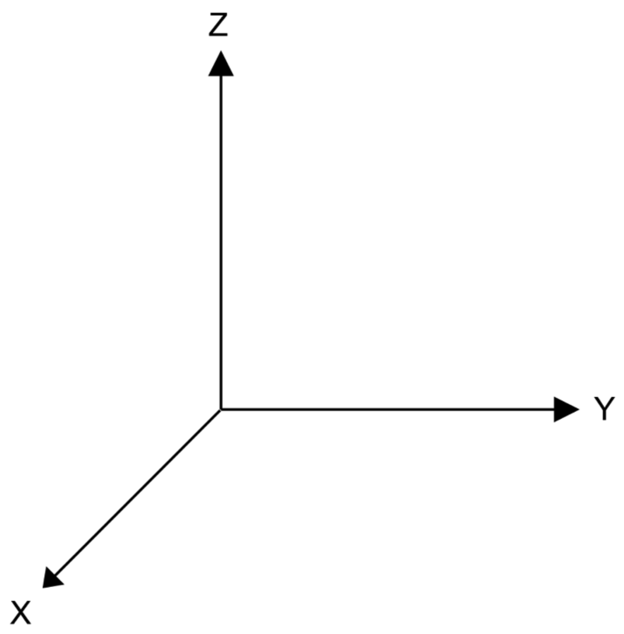


Figure 4. – Three-dimensional Cartesian coordinate system for drop test reference

b) After each of the six drops, examine the SL sample for functionality, the presence of user safety hazards (e.g., glass shards, short circuits, etc.), and damage and record the observations with descriptions and photographs. Superficial damage (minor scrapes or “popped off” components that can easily be put back in place) should not be noted; only note damage that is permanent and non-superficial.

14.3.1.5 *Calculations*

No calculations are made for the drop test.

14.3.2 *Switch and Connector Test*

Each SL sample switch and/or connector is cycled 1 000 times and examined for functionality, user safety hazards, and damage.

14.3.2.1 *Equipment requirements*

Camera

14.3.2.2 *Test prerequisites*

At the start of the switch and connector test the SL samples should be fully functional and have sufficient charge to check for functionality throughout the test.

NOTE — This test is destructive. If the SL has passed the drop test and fails in thistest one more identical sample may be asked from the manufacturer at this stage and in case the other sample also fails this test the sample will be considered fail.

14.3.2.3 *Apparatus*

No apparatus is required for the switch and connector test.

14.3.2.4 *Procedure*

a) Cycle each of the SL sample’s unique switch(es) and/or connector(s) 1 000 times.

b) If damaged is observed during the testing, record the observations with descriptions and photographs. Superficial damage (minor scrapes or "popped off" components that can easily be put back in place) should not be noted; only note damage that is permanent and non-superficial

c) - Continue testing until the product fails to function, a user safety hazard develops (e.g., short circuit), or 1 000 cycles are achieved.

NOTE—If potential damage cannot instantly be observed during testing (e.g., damage to a PV module or mobile phone connector), check for SL sample functionality after every 100 cycles.

14.3.2.5 *Calculations*

No calculations are made for the switch and connector test.

14.4 Reporting

Report the following in the mechanical durability test report

a) Results for tested SL aspects for samples 1 through n
   1) Drop Tests:
      i) Functions after each drop (pass/fail)
      ii) No damage present after each drop (pass/fail)
      iii) No user safety hazard present after each drop (pass/fail)
   2) Switch / Connector Tests:
      i) Cycles achieved for each switch and/or connector
      ii) Functions after test (pass/fail)
      iii) No damage present after test (pass/fail)
      iv) No user safety hazard present after test (pass/fail)

b) Figures
   j) Photographs of observed user safety hazards and/or SL sample damage

15 LUMEN MAINTENANCE TEST

15.1 Background

An important performance metric for LED lights is consistent luminous flux over the product's lifetime. The lifetime of LEDs is mainly influenced by electrical operating conditions and thermal management. Further criteria, which accelerate degradation, include the quality of the phosphor used in white LEDs and the UV resistance of the housing. Assuming that an overall lifetime of 5 years and a daily burn time (DBT) of 4 h are achieved, this results in a total operation time of 7 300 h.

Examination of the lumen maintenance is performed in a long-term test. Because of time constraints, it is generally not practical to measure degradation over the entire expected lifespan of a product. The test methods described in this module monitor light output over a fixed period of operation in order to identify and flag products that are found to suffer significant lumen depreciation.

For the 2 000 h test, a provisional L_{70} judgment can be made at 1 000 h for products that maintain a 95 % lumen maintenance average across all tested samples. Testing has shown that these products are very likely to have L_{70} greater than 2 000 h.

Several of the tests used to evaluate solar LED products are relatively short-term, thus allowing a single test sample to be used on several different tests. Because the lumen maintenance test requires a sample to be dedicated for such a long period of time (up to 12 weeks), it is recommended that test samples are dedicated to this test and not utilized for other testing.

15.2 Test Outcomes

The lumen maintenance test outcomes are listed in Table 10

Table 10 – Lumen maintenance test outcomes
(*Clause* 15.2)

Sl. No. (1)	**Metric (2)**	**Reporting Units (3)**	**Notes (4)**
i)	Lumen maintenance at 2 000 h	%	The percentage of initial light output (time = 0 h) that the product generates at the end of the test (time = 2 000 h)
ii)	Luminous flux at 2 000 h	Lumens (lm)	--
iii)	Lumen maintenance at 1 000 h (provisional results)	%	A provisional L_{70} rating ($L_{70} \geq 2\,000$ h) can be given to products with a lumen maintenance of ≥ 95 % at 1 000 h

15.3Procedure

Full screening lumen maintenance characterization involves SLs to be tested for 2 000 h. For 2 000 h tests, a provisional rating is provided after 1 000 h.

15.3.1 *Equipment Requirements*

Integrating sphere

DC voltmeter

DC ammeter

15.3.1.1 *Full Screening test procedure*

a) The SL battery is replaced by a laboratory power supply that is set to deliver the SL's standard battery voltage.
b) The luminous flux is measured using an integrating sphere system.
c) The minimum frequency at which the luminous flux of the SL ambient temperature,SL voltage,and current are measured and recorded (Refer table 11)

Table 11 – Lumen maintenance test minimum frequency of measurement for full screening test
(*Clause* 15.3.1.1)

Sl. No (1).	Measurement number (2)	Time interval (h) (3)	Cumulative time (h) (4)
i)	1	0.33 (20 min)	0
ii)	2	24	24
iii)	3	48	72
iv)	4	48	120
v)	5	48	168
vi)	6	48	216
viii)	7	168	384
ix)	8	168	552
x)	9	168	720
xi)	10	168	888
xii)	(optional)	112	1000
xiii)	11	168	1056
xiv)	12	168	1224
xv)	13	168	1392
xvi)	14	168	1560
xvii)	15	168	1728
xviii)	16	168	1896
xix)	17	104	2000

15.4 Calculations

Lumen maintenance is calculated by dividing the final light output reading by the initial light output reading and is always reported along with the test duration.

If the light output of the SL ever drops below 70 % of the initial reading, then operating hours at which this occurs should be reported as L_{70}. For example, if the initial reading was 1 000 lx, and readings dropped to 700 lx after 720 h, then L_{70} = 720 h.

If the light output of the SL at the end of the 2 000 hour test is greater than 70 % of the initial reading, the L_{70} rating will then be L_{70} > 2 000 h.

For the 2 000 h test, a provisional L_{70} > 2 000 h rating can be given to products that have a lumen maintenance ≥ 95 % at 1 000 h.

15.5 Reporting

Report the following in the lumen maintenance test report:

a) Results for tested SL aspects for samples
   1) Drive current (A)
   2) Drive voltage (V)
   3) Waiting time (min)
   4) Initial, constant-voltage luminous flux (lm)
   5) Lumen maintenance (note if at 1 000 or 2 000 h) (%)
   6) Final, constant-voltage luminous flux (lm)
   7) Coefficient of variation of sample results for each SL aspect tested (%)

b) Figures

   Plot the lumen maintenance versus time graph

ANNEX A

Manufacturer self- reported information

A.1 Background

Having proper manufacturer information is important for communication throughout the testing process as well as for understanding key product information and any certifications the manufacturer's lab or product may have. To this end, there are three categories of self-reported information: manufacturer information, product information, and manufacturer self-certification regarding either the manufacturing lab or product.

A.2 Outcomes

The manufacturer self-reported information outcomes are listed in Table A1.

Table A1 – Manufacturer self-reported information outcomes

Metric	Notes
Manufacturer information	Record all provided manufacturer information
Product information	Record all provided product information
Self-certification information	Record all manufacturer or product certifications

A.3 Solicited information

A.3.1 Confidential information (not released publicly)

A.3.1.1 Manufacturer information

a) Manufacturer company physical address

b) .Contact person name

c) Contact person position at company (i.e., job title)

d) Contact telephone number, Contact fax number and Contact e-mail address

A.3.1.2 Product information

a) Typical product shipping point of origin

b) Product driver type

c) Battery charge control methods (i.e., deep discharge protection and/or overcharge protection)

d) Description of battery charge control methods

A.3.2 Public information (may be released publicly)

A.3.2.1 Product information

a) Product name

b) Product model number

c) Battery chemistry (SLA, NiMH, etc.) and full information

d) Complete information of the LED used i.e. make, model, country of origin and full technical specifications

e) All product charging system types (e.g., solar module, AC power etc.)

f) If the product has AC power charging, is an adapter included?

g) If the product has solar charging, what active material is used in the PV module (e.g., mono-Si, poly-Si, CIS, etc.)

h) All included product features (e.g., mobile phone charging, radio, etc.)

i) All optional product features (e.g., mobile phone charging, radio, etc.)

j) Description of product warranty terms, including duration

A.3.2.2 Manufacturer certifications

These certifications should be accompanied with supporting documentation, such as copies of the original certifications, letters from an appropriate organization, or self-certification.

a) All manufacturer company certifications and markings

b) All product certifications and markings (e.g., UV-resistant plastic, UV-free LEDs, high-temperature batteries, module qualification test certificate etc.)

ANNEX B

Battery cycling recommended practices

B.1 Background

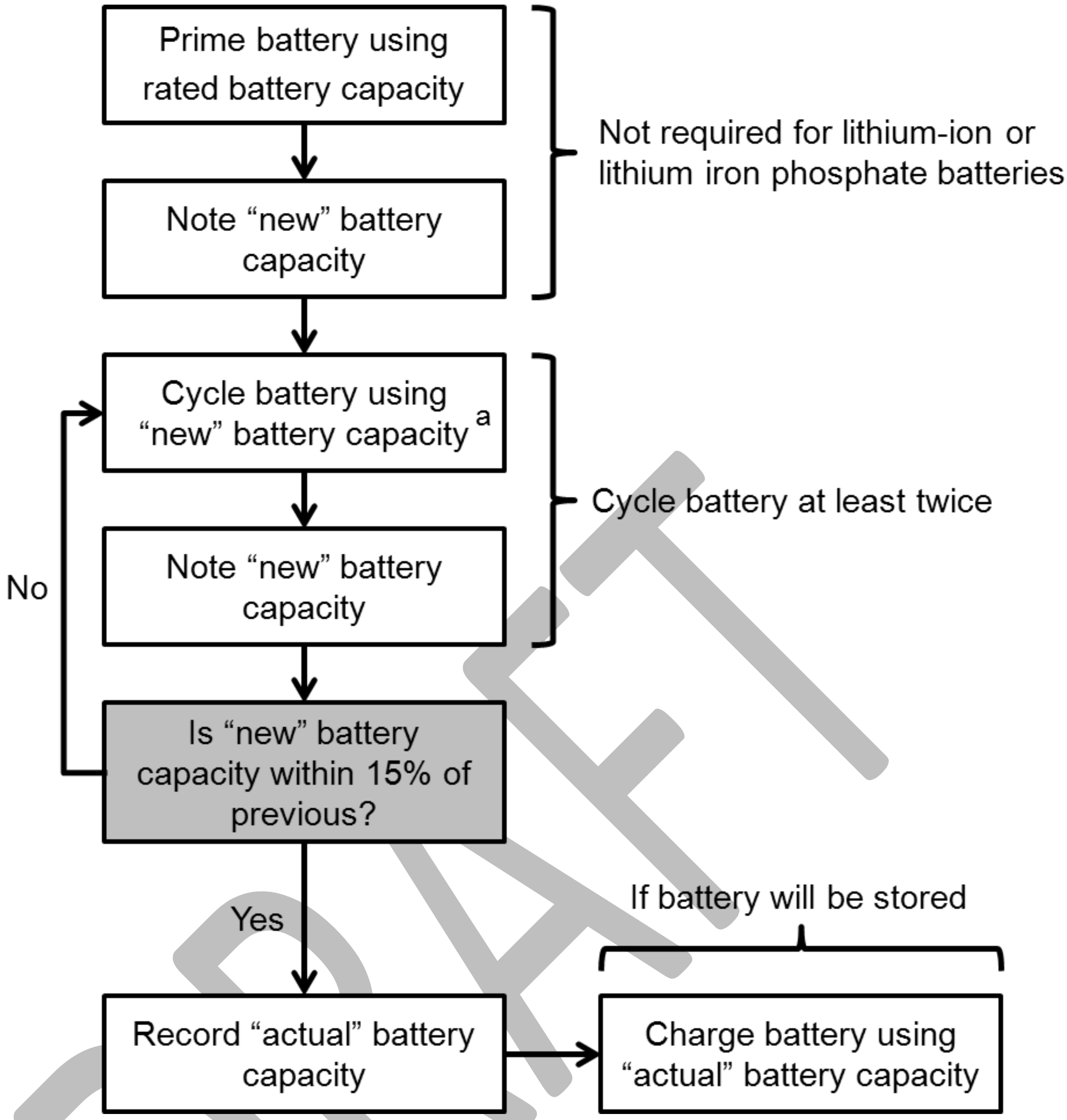
During the battery test the SL’s battery is cycled numerous times in order to determine the battery’s actual capacity and storage efficiency. In addition to the charge-discharge guidelines specified in the battery test , the battery cycling recommended practices **Annexure C** provides further information to ensure that the battery is not damaged during testing and the person conducting the test is safe.

B.2 Charge-discharge specifications by battery type

Table1.contains battery cycling information specific to the five common types (i.e., chemistries) of batteries. This information should be used in conjunction with the charge and discharge rates specified in the battery test procedures.

Table 1 Recommended battery cycling specifications according to battery chemistry

Battery type	Maximum standby voltage	Maximum charge voltage	End of charge / topping charge rate	End of discharge voltage
Sealed lead-acid	2.25	2.40	0.05 I_t	1.80
Lithium-ion	4.05	4.10	0.05 I_t	3.00
Lithium iron phosphate	3.55	3.60	0.01 I_t	3.00
Battery type	**Negative slope (mV/cell)**	**End of discharge voltage (V/cell)**	**End of recondition (V/cell)**	**Charge method**
Nickel-metal hydride	8.00	1.00	0.40	Reverse load pulse at 9 %
Nickel-cadmium	8.00	1.00	0.40	Reverse load pulse at 9 %



Key

a Use the rated battery capacity for the first cycle of lithium-ion and lithium iron phosphate batteries