

PV GAP
RECOMMENDED
SPECIFICATION

PVRS 5A

2003-12

**Lead-acid batteries for solar photovoltaic
energy systems - General requirements
and methods of test for modified
automotive batteries.**

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Description: Battery, Photovoltaic cells, Electric Power Systems

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FOREWORD

- 1) PV GAP (Global Approval Program for Photovoltaics) is a not-for-profit international organization, dedicated to the sustained growth of global photovoltaic (PV) markets to meet energy needs world-wide in an environmentally sound manner. Its mission is to promote and encourage the use of internationally accepted standards, quality management processes and organizational training in the design, fabrication, installation, sales and services of PV systems. To this end, it partners with PV related industries, international organizations, testing laboratories, government agencies, financing institutions, non-governmental organizations, and private foundations, in developing and developed countries.
- 2) PV GAP co-operates closely with the International Electrotechnical Commission (IEC) in respect of standardization (principally with IEC Technical Committee N° 82, Solar Photovoltaic Energy Systems) and certification (presently with the IEC Quality Assessment System for Electronic Components, IECQ-CECC. From January 2004, co-operation with IECQ-CECC will be transferred from IECQ-CECC to the IEC System for Conformity Testing and Certification of Electrical Equipment and Components (IECEE)).

PV GAP publishes specifications that have been developed and recommended by experts from the PV industry and other organizations, to be used as interim, recommended specifications until the corresponding IEC standards can be completed. The acceptance of these PV GAP "Recommended Specifications" is voluntary. PV GAP only recommends these specifications but disclaims any liability for their utilization.

It should be noted that, as soon as a corresponding IEC standard is issued, the PV GAP "Recommended Specification" is withdrawn. This is announced on the PV GAP website www.pvgap.org, together with information about the new IEC standard.

- 3) The present PV GAP Recommended Specification has been endorsed by the PV GAP Technical Committee, and approved by the PV GAP Executive Board. Members of the Technical Committee and the Executive Board bodies are listed on the website www.pvgap.org.
- 4) General enquiries about PV GAP may be addressed to the publisher, which is the PV GAP Secretariat, c/o IEC Central Office, 3 rue de Varembé, Box 31, CH 1211 Geneva 20, Switzerland, E-mail rk@iec.ch, TP +41 22 919 02 16, TF +41 22 919 03 01.

The publisher will be pleased to receive any comments from users of this PV GAP Recommended Specification. All comments will be acknowledged.

Whilst every effort has been made to ensure the accuracy of the contents of this PV GAP Recommended Specification, the publisher can accept no responsibility for any errors that may have occurred.

0.1 Introduction

Uganda National Bureau of Standards (UNBS) is a parastatal under the Ministry of Tourism, Trade and Industry established by the Act of Parliament of 1983, of the Laws of Uganda. UNBS is

- (i.) a member of International Organisation for Standardisation (ISO) and
- (ii.) a contact point for the WHO/FAO Codex Alimentarius Commission on Food Standards, and
- (iii.) the national Enquiry Point on TBT.SPS Agreements of the World Trade Organisation (WTO).

The work of preparing Uganda standards is carried out through Technical Committees. A Technical Committee is established to deliberate on standards in a given field or area and consists of representatives of consumers, traders, academicians, manufacturers, Government and other stakeholders.

Draft Uganda standards adopted by the Technical Committee are widely circulated to stakeholders and the general public for comments, which are reviewed before recommending them to the National Standards Council for declaration as national standards.

Batteries for photovoltaic systems are widely used especially because the national electricity grid has not reached many parts of the country. The harnessing of solar energy can greatly raise the standards of living in those areas. The use of these batteries for domestic lighting, power and pumping is to be encouraged.

It is with this in mind that it has been found necessary to prepare this standard.

0.2 Committee membership

The following organisations were represented on the Technical Committee

Physics Department, Makerere University Kampala- Chairman

Department of Electrical Engineering, Makerere University Kampala

Uganda Telecom Limited

Uganda Electricity Distribution Company

Ministry of Energy and Mineral Development

Uganda Photovoltaic Pilot Project for Rural Electrification (UPPPRE)

Solar Energy (U) Limited

INCAFEX Solar

Uganda Renewable Energy Association (UREA)

MAGRIC (U) Limited

Lwanga Electronics and Electrical Machinery

Uganda Batteries Limited

0.3 PV GAP's photovoltaic Recommended Specifications (PVRS)

The PV GAP Technical Committee (TC) is an open ended Committee. Membership of the PV GAP TC is open to any qualified person from any country with interest to help to develop a consensus for a proposed PVRS. After the TC reaches consensus, the PVRS draft is submitted to the PV GAP Executive Board for approval.

Lead-acid batteries for solar photovoltaic energy systems - General requirements and methods of test for modified automotive batteries.

1. Scope

This PVRS gives general information relating to the requirements of lead-acid batteries used in photovoltaic (PV) solar energy systems and the test procedure applied for the verification of battery performance needed to determine whether a battery is well fitted for solar PV application.

This PVRS does not include specific information relating to battery sizing, method of charge or PV system design.

NOTE 1: This PVRS is also applicable to modified lead-acid car/automotive batteries intended for use in PV systems.

NOTE 2: Batteries qualified to this PVRS are suitable for PV application. The test applied for obtaining the PV GAP mark for batteries is intended to qualify batteries for PV application. Whether or not a battery in real application operates according to specification and to client satisfaction can only be verified in conjunction with the system set up. For the application in PV stand-alone Solar Home Systems (SHS), such a performance test is under consideration in IEC TC 21 and should be published in the near future as IEC 61427 2nd edition.

NOTE 3: This PVRS fills a gap in qualifying lead-acid batteries to be used in PV application. In the future, three standards will cover the issue in completely qualifying batteries as a type approval for specific PV application: (i) IEC 62093, "Balance of System (BOS) components for PV systems – design qualification natural environments", Second Committee Draft (CD2), under consideration. This standard will be used to qualify batteries with regard to safety, shipping compatibility etc; (ii) This PVRS is intended to separate batteries suitable for PV application in general for PV application from batteries which are not suitable, with a minimal test requirement with regard to cost and time, and (iii) type approval tests, which qualify the battery to work in conjunction with the other system components in system configuration (for Solar Home System a type approval test is in preparation to be published).

2. Normative references

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply.

IEV 60050(486):1991, *International Electrotechnical Vocabulary (IEV) - Chapter 486: Secondary cells and batteries*

IEC 60051-2:1984, *Direct acting indicating analogue electrical measuring instruments and their accessories - Part 2: Special requirements for ammeters and voltmeters*

IEC 60359:1987, *Expression of the performance of electrical and electronic measuring equipment*

IEC 60485:1974, *Digital electronic d.c. voltmeters and d.c. electronic analogue-to-digital converters*

IEC 60721-1:1990, *Classification of environmental conditions - Part 1: Environmental parameters and their severities*

IEC 60896-1:1987, *Stationary lead-acid batteries - General requirements and methods of test - Part 1: Vented types*

IEC 60896-2:1995, *Stationary lead-acid batteries - General requirements and methods of test - Part 2: Valve-regulated types*

IEC 61836:1997: *Solar photovoltaic energy systems - Terms and symbols*

3. Definitions

For the purpose of this PVRS, the definitions and terms applicable to secondary cells and batteries as given in IEC 60050(486), those for photovoltaic generator systems as given in IEC 61836 as well as the following definitions apply.

3.1 duty cycle

sequence of operating conditions to which a cell or battery is subjected. This includes factors such as charge and discharge rates and conditions, depth of discharge, numbers and types of cycles, temperatures and length of time in open circuit state

3.2 duty cycle capacity

capacity of a cell or battery required to meet the duty cycle requirements

3.3 ampere-hour capacity

the number of ampere-hours which a cell or battery can deliver under specified conditions, i.e. charging conditions, the rate of discharge, temperature and final voltage

3.4 battery capacity

the total number of ampere-hours that can be withdrawn from a fully charged battery at a given rate of discharge to a specified cut- off voltage

3.5 C_{10}

the rated capacity of a battery specified at a constant discharge current which would fully discharge the battery in 10 h

3.6 days of autonomy

the number of days which a fully charged battery can support the load with no power received from external sources e.g. photovoltaic (PV) array

3.7 deep cycle battery

a battery, which is designed so that up to 20 % of the rated ampere-hours can be removed on a regular daily basis without damage or unduly shortening life

3.8 end-of-charge voltage

the cell or battery voltage at which charging is normally terminated by the charging source or continued at constant voltage condition

3.9 rated capacity

the full amount of energy a battery can deliver when fully charged and when discharged down to a minimum cut-off voltage under specified conditions of temperature, current and final voltage

3.10 terminal voltage

the voltage across the terminals at any time, whether the battery is charging, discharging, or in open circuit

3.11 charging and discharging efficiency test

the efficiency test which is carried out in such a manner that the specimen in the state of full charge is discharged to the cut-off voltage of discharge, charged from this state by an ampere-hour equal to the discharged ampere-hour, then discharged again to the cut-off voltage of discharge

3.12 PSOC (partial state of charge) efficiency test

the efficiency test, which is carried out over a range of charging state, specified, by taking the operation under the partial state of charge (or discharge), which occurs under the service conditions in a photovoltaic system into consideration

3.13 PSOC (partial state of charge) cycle number test

the test which is carried out to confirm the operation for photovoltaic system by means of the charge and discharge pattern estimated from the solar radiation conditions in typical SHS application, typically in tropical areas, by taking the operation under the partial state of charge (or discharge) which occurs under the service conditions in a photovoltaic system into consideration

3.14 PSOC (partial state of charge) ampere-hour efficiency

the ratio of the discharged ampere-hour to the charged ampere-hour obtained in A.5 PSOC efficiency test

3.15 PSOC (partial state of charge) watt-hour efficiency

the ratio of the discharged watt-hour to the charged watt-hour obtained in A.5 PSOC efficiency test

3.16 partial discharge end voltage

the voltage at which the discharge shall be completed in A.5 PSOC efficiency test

3.17 partial charge end voltage

the voltage at which the charge shall be completed in A.5 PSOC efficiency test

4. General operating conditions

A battery in typical stand-alone photovoltaic system operating under average site weather conditions may be subjected to the following condition:

4.1 Autonomy time

Batteries are used to supply energy under specified condition for period of time from 1 day to 15 days with minimum or almost zero solar irradiation.

4.2 Typical charge and discharge current

Typical charge current generated by the photovoltaic generator, especially often found in Solar Home System (SHS) applications

- | | |
|-----------------------------------|--------------------------------|
| a) Typical maximum charge current | $I_{20} = C_{20}/20 \text{ h}$ |
| b) Typical average charge current | $I_{50} = C_{50}/50 \text{ h}$ |

Discharge current determined by the load

Typical average discharge current $I_{120} = C_{120}/120 \text{ h}$

Depending on system design, the charge and discharge current may vary in a wide range.

4.3 Daily cycle

The battery is normally exposed to daily open cycle with:

- Charging during daylight hours
- Discharging during night time hours
- Typical daily discharge can be in the range of 2 % to 20% of the battery capacity

4.4 Seasonal cycle

Battery may be exposed to a seasonal cycle of state of charge because of varying average charging condition as follows.

In the period of low solar irradiation, for instance during rainy season, stand-alone system will yield low energy production. The state of charge of the battery (available capacity) can go down to 20 % of the rated capacity.

Periods with high solar radiation as in dry seasons will bring the battery up to complete or almost fully charged condition. Under these conditions, the battery can get overcharged if not properly operated by the charge controller.

4.5 Period of high state of charge

During dry seasons with high solar irradiation, for example, the battery will be operated at a high state of charge typically between 80% and 100 % of rated capacity.

A voltage regulator system normally limits the maximum battery voltage during the recharge period.

NOTE: In a self-regulated PV system the battery voltage is not limited by BCR but by the characteristic of the PV modules.

The system designer normally chooses the maximum battery voltage with regard to the conflicting requirement of recovering to maximum state of charge as early as possible in the charging season but without substantially overcharging the battery. The overcharge increases gas production resulting in water consumption in vented cells. In valve regulated lead-acid cells, the overcharge will cause increase in gas emission and heat generation. Typically the maximum cell voltage is limited to 2.4 V per cell for lead-acid battery. Some battery regulator allows the battery voltage to exceed these values for a short period as an equalizing or boost charge, which can also help avoiding stratification. Temperature compensation should be used if the operating battery temperature deviates significantly from 20°C.

4.6 Period of sustained low state of charge

During period of low solar irradiation, the energy produced by the solar array may not be sufficient to recharge the battery. The battery state of charge will then decrease and the cycling will take place at low state of charge.

4.7 Stratification electrolyte

Electrolyte stratification may occur in lead-acid battery. In vented lead acid battery electrolyte stratification can be avoided by electrolyte agitation or periodic over-discharge while in service.

What ever the battery type, vented or sealed, flat or tubular, one of the key words is stratification. It relates to both the battery and the charge control strategy. If one lets the electrolyte stratify, with a poor recharge, one will get irreversible sulphation, and therefore a quick irreversible capacity decrease.

4.8 Transportation

Batteries are often operated in inaccessible sites, remote and difficult to reach by transportation. Batteries may therefore be subjected to a degree of rough handling on their journey to the site. Suitable packaging to protect the batteries may be used during transportation.

Lead-acid batteries may also be transported in dry condition with electrolyte transported separately. When lead-acid batteries should be transported in wet condition, it is recommended only for site, which is not so far away and accessible. Filled batteries should be charged completely prior to delivery, since new owner may over-use the PV system in the first days. Starting already with a poorly charged battery can, unless weather is very favourable and permits fast and complete recharge, lead to quick irreversible capacity decrease.

4.9 Storage

Manufacturer's recommendation for storage should always be observed. In the absence of such information, typical climatic condition may be assumed to be those shown in table 1.

Battery type	Temperature range	Humidity	Battery storage period	
			With electrolyte	Without electrolyte
Lead-acid	-20 °C to 40°C	<95 %	up to 6 month	1 – 2 years (<i>dry charge</i>)

Table 1 Temperature range of battery storage environment condition

For batteries delivered ready filled and charged

Ambient temp. during storage	Maximum storage time before recharge
20°C	6 months
30°C	4 months
40°C	2 months

Filled and charged batteries required periodic recharging. Battery manufacturer should be consulted for interval and method of recharge. A loss of capacity may result from exposure of a battery to high temperature and humidity during storage.

NOTE 1: avoid direct exposure to sunlight during storage of the batteries.

NOTE 2: batteries should always be fully charged prior to delivery and installation in a system, except if dry transportation is preferred.

4.10 Operating temperature

Environmental temperature constitutes an important factor in battery selection and determining the age of battery. The following climatic condition should be considered.

Battery type	Temperature range	Humidity
Lead acid	-20°C to +40°C	< 95%

Table 2. Temperature range of battery condition

5. Capacity

Capacity refers to the number of ampere-hours that a battery can yield for a given end-of-discharge voltage and current and varies with the conditions of use such as electrolyte, temperature, discharge current and final voltage.

Normally manufacturers of lead-acid batteries publish the rated capacity for 10 h discharge. The capacity for a 120 h and 240 h discharge time shall also be provided by the manufacturer, as these times are commonly used in PV typical applications.

Capacity	Current	Discharge period	Final voltage
Ah	A	h	Lead-acid, Volts per cell
C ₂₄₀	I ₂₄₀	240	1,90
C ₁₂₀	I ₁₂₀	120	1,85
C ₁₀	I ₁₀	10	1,75

Table 3 – Typical capacity ratings of batteries in solar applications

6. Endurance in cycles (battery life)

The cycle endurance is the ability of a battery to withstand repeated charging and discharging. Normally the cycle endurance is given for cycles with a fixed depth of discharge and with the battery fully charged in each cycle. The batteries are normally characterized by the number of cycles that can be achieved before the capacity has declined to 80 % of the rated capacity as per table 3 below. In all cases, the number of cycles is based on a depth of discharge of 20%.

The established cycle tests are specified in

- IEC 60896-1 for stationary lead-acid batteries (vented types)
- IEC 60896-2 for stationary lead-acid batteries (valve-regulated types)

In photovoltaic applications the battery will be exposed to a large number of shallow cycles but at a varying state of charge. The cells or batteries shall therefore comply with the requirements of the test described in clause 15 of the present specification, which is a simulation of the PV system operation. The manufacturer shall specify the number of cycles the cells or batteries can achieve before the capacity has declined to 80 % of the rated capacity when tested in accordance with clause 15

Battery type	Number of cycles
SLI modified	1000
SLI low maintenance	1200
Sealed lead acid	3000
Tubular	5000

Table 3 – Number of cycles to be achieved by solar batteries

NOTE: SLI is an acronym for “Starting, Lighting and Ignition”, and is normally referred to as a “ car “ or “automotive” battery

7. Charge control

Excessive overcharge does not increase the energy stored in the battery. Instead, overcharge affects the water consumption in vented batteries and consequently the service interval. In addition valve-regulated lead-acid batteries may dry out resulting in a loss of capacity or overheating.

Overcharging can be controlled by use of proper charge controllers.

The parameters of the regulator shall take into account the effects of the PV generator design, the load the temperature and the limiting values for the battery as recommended by the manufacturer.

Vented lead-acid batteries shall have sufficient electrolyte to cover at least the period between planned service visits. Overcharge in valve-regulated lead-acid batteries shall be carefully controlled to reach optimum lifetime.

The water consumption is measured during the cycle test (see 15.5) and can be used together with the system's design information to estimate the service intervals.

8 Charge retention

The charge retention is the ability of a battery to retain capacity during periods of no charge, i.e. when not connected to a system, during transportation or storage. A battery for solar application shall show a high capability of charge retention. The charge retention shall be stated by the manufacturer and shall meet the requirements of the relevant battery standard.

NOTE: Charge retention may affect the permitted storage and autonomy time.

9. Charge efficiency

Two types of efficiencies are considered:

$$\text{Faradaic efficiency: (Ah efficiency) = } \frac{\text{Discharge capacity (Ah)}}{\text{Recharge capacity (Ah)}}$$

$$\text{Energy efficiency: (Wh efficiency) = } \frac{\text{Discharge capacity (Ah) x } \Sigma \text{ Discharge potential (V)}}{\text{Recharge capacity (Ah) x } \Sigma \text{ Recharge potential (V)}}$$

The objective of such measurements is to assess the battery efficiency at different states of charge. The charge efficiency is the ratio of the quantity of electricity delivered during the discharge of a cell or battery to the quantity of electricity necessary to restore the initial state of charge under specified conditions (see IEC 60896-2-1).

NOTE: Normally data of battery efficiency are often given in Ah and refer to the Faradaic efficiency: (Ah efficiency). The quantity of electricity is then expressed in amperes-hours (Ah).

Where no data are available from the battery manufacturer, the following (Faradaic) efficiencies as given in table 4 may be assumed.

State of charge (SOC)	Efficiency lead-acid cells
90 %	>85 %
75 %	>90 %
<50 %	>95 %

Table 4 –Typical battery Ah-efficiencies at different states of charge at 20 °C and a cycle depth of less than 20 % of the rated capacity.

The data collected during the efficiency tests leads to the following:

- Efficiency values are higher when the cycling is performed at the lower SOC. There is a slight decrease as the average SOC increases. When the gassing voltage is reached, the decrease becomes higher.
- The efficiency depends on the previous history of the battery, efficiency values are higher when the previous cycle is performed at a higher average SOC than the new cycle and lower when the previous cycle is carried out at a lower average SOC. This could be seen as a kind of a "memory effect".
- The faradaic efficiency may exceed 100 % when both previous conditions are met: low SOC and higher previous SOC.

10. Over-discharge protection

Lead-acid batteries shall be protected against over-discharge to avoid capacity loss due to irreversible sulphation. This can be achieved by a low voltage disconnect that operates when the design maximum depth of discharge is exceeded (for final voltages, see table 3).

11. Mechanical endurance

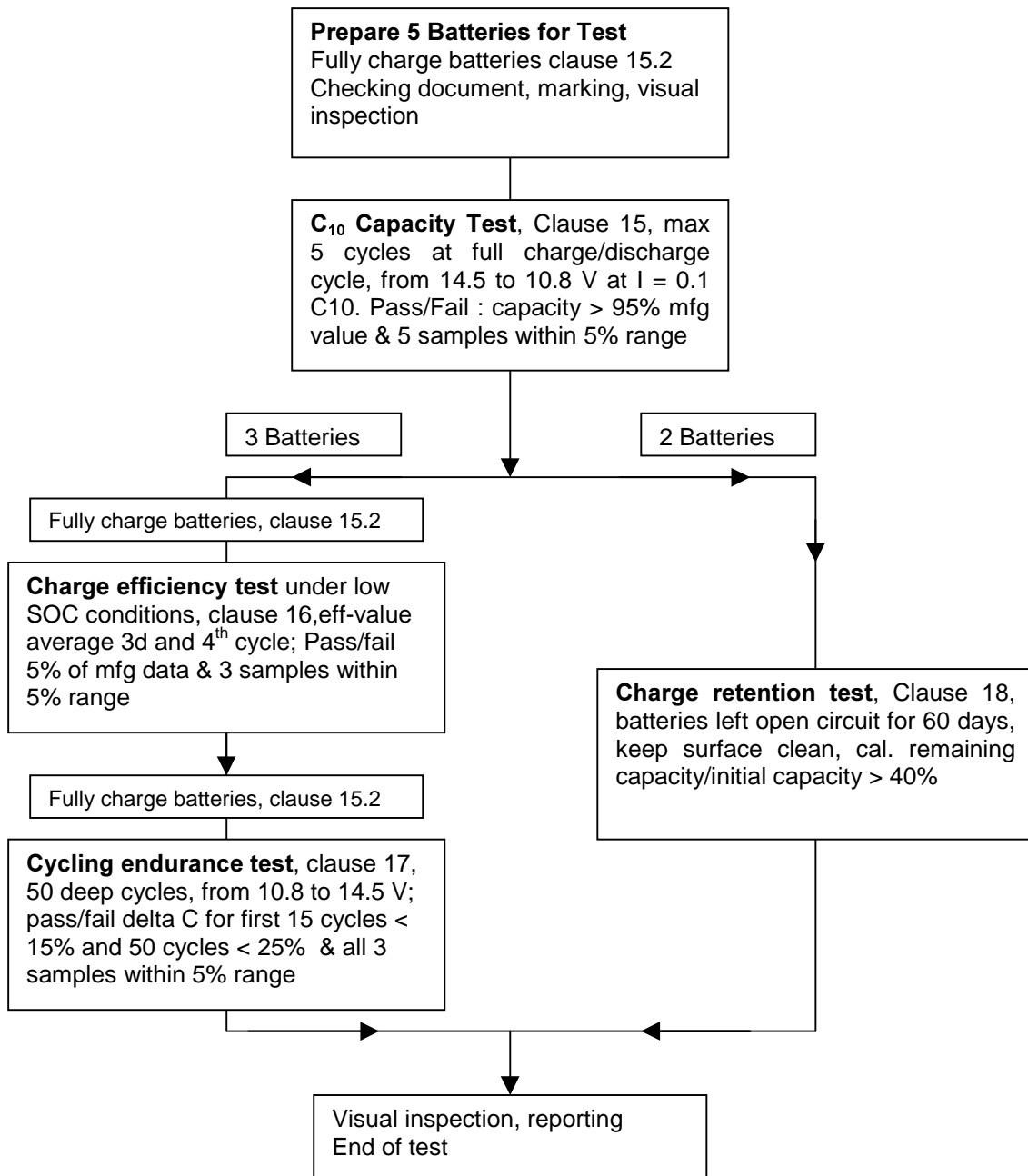
Batteries for solar application shall be designed to withstand mechanical stresses during normal transportation and handling. Additional packing or protection may be required for off-road conditions.

Particular care shall be taken while handling unpacked batteries. Manufacturer instructions shall be observed.

In case of specific requirements regarding mechanical stresses, such as earthquakes, shock and vibration, these should be individually specified or referred to the relevant product standard.

12. Qualification test procedure

To qualify a battery for PV application, a series of total 4 tests must be carried out. The test flow diagram gives an overview, and the individual tests are described further below.



13. Accuracy of measuring instruments

When testing batteries, the parameters and accuracy values given in table 5, shall apply.

Parameters	Accuracy
Voltage	±1 %
Current	±1 %
Temperature	±2 °C
Electrolyte density (vented batteries only)	±0,005 kg/l
Time	±0,1 %

Table 5 - Accuracy of measuring instruments

The accuracy of the measuring instruments when conducting tests shall be in compliance with the relevant IEC standard:

- IEC 60051-2 and 60485 for voltage measurements;
- IEC 60051-2 and 60359 for current measurements.

14. Preparation and maintenance of test samples

Test samples shall be prepared in accordance with the following established procedures in the following standards:

- IEC 60896-1 for stationary lead-acid batteries (vented types);
- IEC 60896-2 for stationary lead-acid batteries (valve-regulated types);

The test sample shall be set up in accordance with the manufacturer's instructions. Any special conditions affecting the operation of the battery on site may also need to be included in the test.

Placing of Batteries During Tests.

Throughout the duration of the tests, the battery shall be placed in a water bath at a temperature of 25 ± 2 °C. The terminal base of the battery shall be at least 15 mm but no more than 25 mm above the level of the water. If several batteries are in the same water bath, the distance between them shall be at least 25 mm.

15. Capacity test

15.1 Batteries shall be prepared in accordance with clause 14.

15.2 The test shall be carried out on new and fully charged batteries. Charging shall be done as follows: charge with $I = 0.1 * C_{10}$ until $V > 14.5$ Volts, and then charge during another 3 hours at 14.5 V.

15.3 The battery shall then be discharged within about 10 hours after fully charging at a

current $I_N = 0.1 * C_{10}$ until the terminal voltage falls to 1.8 volts per cell or 10.8 Volt for 12V block. This current should be kept constant $\pm 1\%$ during discharging.

Note: Manual setting of discharge current is only admitted if tolerance will not exceed $\pm 1\%$, which requires very attentive surveillance during the test period.

- 15.4 The voltage between terminals of the cells or battery shall be either recorded automatically against time or taken by reading from a voltmeter. Readings shall be made at least at 25%, 50% and 80% of the calculated discharge time;

$$t = \frac{C_{nom}}{I_{nom}} \text{(hour)}$$

and then at suitable time interval, which permits detection of the transition to the final discharge voltage V_{akh} . The voltage values may be used to calculate the energy efficiency of a battery.

- 15.5 The uncorrected capacity C (Ah) at the average temperature of 25°C is then calculated as a product of discharge current (in Ampere) and discharge time (in hour); $C_a = I_n \times t$ in Ah.

A new battery being repeatedly charged and discharged shall supply at least:

$$C_a = 0,95 C_{nom} \pm 5\% \text{ at the first cycle}$$

$$C_a = C_{nom} \pm 5\% \text{ at or before fifth cycle}$$

If the rated capacity as declared by the manufacturer is not achieved, the charge/discharge cycle shall be repeated maximal five times.

Pass / Fail.

Batteries are considered to pass this test if

(i) the rated capacity is within $\pm 5\%$ of manufacturer's specification in any of the first five-charge/discharge cycles and

(ii) the values from the five test samples are within a band of plus/minus 5% of the average value calculated from the five values of the five tested batteries.

16. Charge efficiency test at low state of charge conditions

An efficiency test procedure under low states of charge assesses the ability of batteries to deliver during discharge the energy previously charged in.

16.1 Cycling conditions:

- Initial cycle: recharge according to 15.2 until 100 % of SOC,
- discharge at 0.1 C/10 until 1.8 V per cell (= 0 % of SOC). This current should be kept constant $\pm 3\%$ during discharging

- recharge at 0.1 C/10 (rated C/10) until 50 % of the rated C/10 capacity value is reached. This current should be kept constant $\pm 3\%$ during charging.
- discharge at 0.1 C/10 (rated C/10) until 1.8 V per cell. This current should be kept constant $\pm 3\%$ during discharging.

An average efficiency value shall be calculated from the 3rd and 4th cycle efficiency values.

16.2 Cycling duration:

- If the efficiency values are stable after four cycles, then the average value can be calculated from the efficiency values obtained at the 3rd and 4th cycle.
- If the efficiency values are not stable after four cycles, max. additional 5 cycles will be needed until two consecutive values are constant (difference less than 5 %).

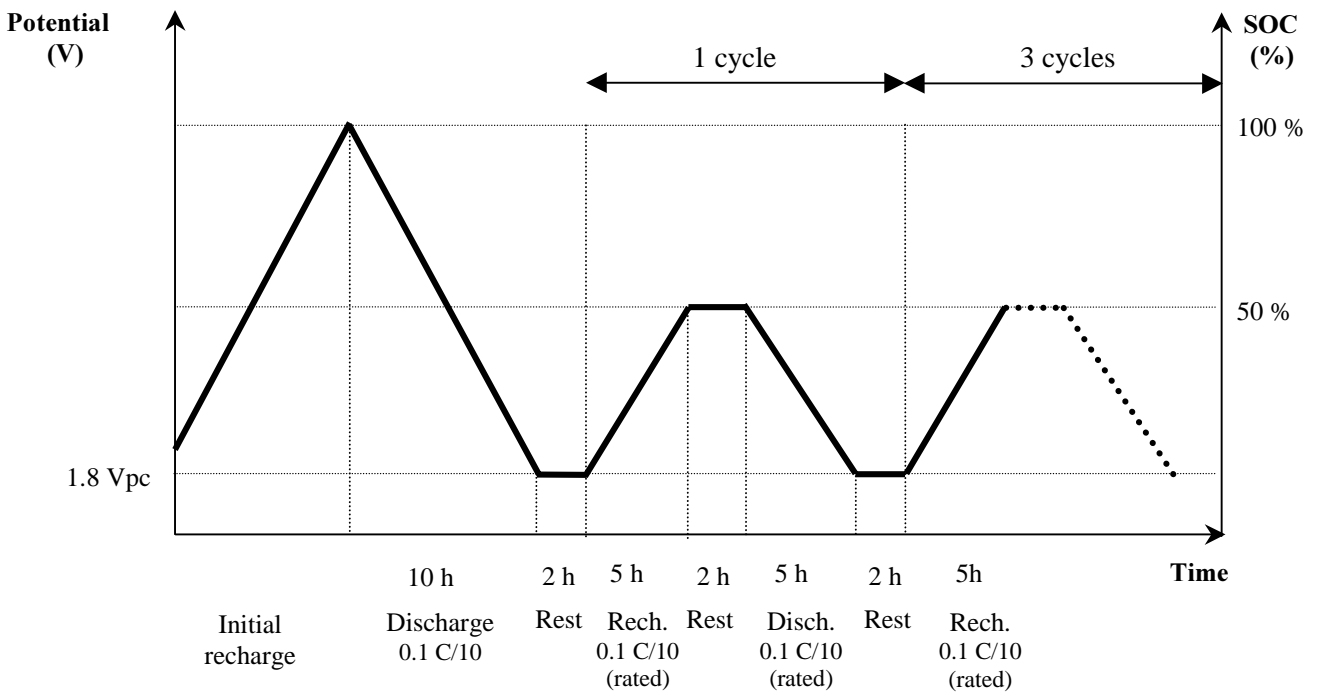


Fig: Cycling conditions of the low state of charge efficiency test procedure.

16.3 Pass/Fail:

- (i) Batteries are considered to pass this test if the measured efficiency is within $\pm 5\%$ of the following values:

	Flat plates batteries	Tubular plates batteries
Faradaic efficiency	0.96	0.94
Energy efficiency	0.89	0.84

and

- (ii) the values from the three test samples are within a band of plus/minus 5% of the average value calculated from the three values of the three tested batteries.

17. Cycling endurance test

This test is an accelerated cycling endurance test to eliminate unsuitable batteries for solar applications with a test period in less than 1 000 hours, or than 1.5 month. The acceleration test method is based on a cycling close to nominal C10 capacity, but limited to 50 cycles. (The acceleration test is NOT based on cycling at elevated temperature). The large cycle amplitude has also the advantage that each cycle is almost a complete capacity test. This has the positive consequences that subsequent capacity tests are not necessary, since each cycle is almost a full capacity test and can be used to plot capacity versus number of cycles.

17.1 Batteries should be prepared in accordance with clause 13.

17.2 The test shall be carried out on new fully charged batteries. Charging shall be done as follow: charge with $I = 0.1 * C10$ until $V = 14.5$ Volts, and then charge during another 3 hours at 14.5 V.

17.3 The battery shall then be discharged within about 9 to 10 hours after fully charging at a current $I_N = 0.1 * C10$ until the terminal voltage falls to 10.8V. This current should be kept constant $\pm 3\%$ during discharging. Capacity in Ah of discharge shall be calculated.

17.4 The battery shall then be recharged with $I = 0.1 * C10$ until $V=14.5$ Volts. This current should be kept constant $\pm 3\%$ during charging. Continue charging for a further 30 minutes for equalizing, prior to starting the discharging phase.

Steps 17.3 and 17.4 shall be repeated 50 cycles. Of each of the first 20 cycles, and then minimal of each of the 5th cycle of C10 capacity values shall be plotted against number of cycles.

Pass/Fail criteria

Batteries are considered to pass this test if:

- (i) Capacities between 1st and 15th cycle does not decrease by more than 15% and
- (ii) Capacity between 1st and 50th cycle does not decrease by more than 25%.
- (iii) The values from the three test samples are within a band of plus/minus 5% of the average value calculated from the three values of the three tested batteries.

Note: The battery at this point has seen 5 deep cycles from the initial capacity test, 5 partial cycles from the efficiency test and 50 deep cycles from the accelerated cycling endurance test.

18. Charge retention test

- 18.1 Surface of specimen, clean and dry the surfaces
- 18.2 Ambient temperature during storage, $(25 \pm 5) ^\circ\text{C}$
- 18.3 Fully charge battery according to 15.1 and 15.2.
- 18.4 Storage period, 60 days with the circuits open. Do not carry out auxiliary charge before commencement of discharge.
- 18.5 Capacity test after storage
- 18.6 Obtain the charge retention characteristics from the following formula

$$\eta_{\text{ST}} = \frac{C_r}{C_a} \times 100 \quad (1)$$

where,

- η_{ST} charge retention rate,
- C_a capacity measured before storage in capacity test (Ah)
- C_r capacity measured after storage without auxiliary charge (Ah)

Pass/Fail: Batteries are considered to pass this test

- (i) if η_{ST} is $> 40\%$ and
- (ii) the values from the two test samples are within a band of plus/minus 5% of the average value calculated from the two values of the two tested batteries.

19. Marking and Documentation verification

19.1 Each battery shall be clearly and permanently marked with the following information:

- a) The name of the manufacturer or supplier or his trademark, country of origin
- c) Type of battery (e.g. deep cycle, vented)
- d) Date of manufacture
- e) Rated capacity C_{10}
- f) Nominal voltage
- g) Recommended maximum voltage
- h) Recommended minimum voltage

19.2 Information to be supplied by the manufacturer or supplier

The manufacturer or supplier shall give the following information:

- a) recommended depth of discharge
- b) cycle life and condition of testing
- c) maximum charge voltage, float voltage and load disconnect voltage
- d) temperature compensation curves
- e) type of battery cell
- f) density of electrolyte
- g) documented battery recycling program

The manufacturer shall advise if there are special considerations for the initial charging of batteries with only the solar array available as the power source (should be avoided for SHS application).

Pass / Fail:

Batteries are considered to pass this test if marking and documentation is within specification given above. Minimal documentation as required in 19.2 must be also in English.

Annex A (informative, Classification of tests)

Tests are classified as stated below.

A.1 Rated capacity test

The test to confirm the rated capacity stated on the nameplate or the like in such a manner that the specimen is discharged at the rated discharge hour rate current to the specified cut-off voltage of discharge.

A.2 Ten-hour rate capacity test

Such a test that the capacity of a lead-acid battery with rated capacity different from 10-hour rate capacity is measured at 10-hour rate current.

A.3 Charge retention rate test

Such a test that the specimen is allowed to stand after complete charge for a certain period, then discharged, and the charge retention rate is obtained from the difference between the capacity before standing and the capacity after standing.

A.4 Charge and discharge efficiency test

Such a test that the specimen is discharged from the state of full charge to the cut-off voltage of discharge, charged by an ampere-hour equal to the discharged ampere-hour in the above procedure, then discharged again to the cut-off voltage of discharge, and the charging and discharging efficiency is obtained from the charged ampere-hour and the discharged ampere hour.

A.5 PSOC (partial state of charge) efficiency test

The test for measurement of the charging and discharging efficiency over the specified range of charged state.

A.6 PSOC (partial state of charge) cycle number test. The test to confirm that the specimen operates without any trouble as the lead-acid battery for photovoltaic system by means of the charge and discharge pattern estimated from the solar radiation conditions in the place of use.**A.7 Over-charge life test**

The accelerated life test by overcharge to evaluate the life of positive electrode grid.

A.8 Over-discharge test

The test for performance of recovery from over-discharged state.

A.9 Gas recombination efficiency test

The test to evaluate the ability to return oxygen gas and hydrogen gas produced during charging of a sealed type lead-acid battery to water by means of recombination or absorption of oxygen gas into the cathode (negative pole).

A.10 Safety valve operation test

The test to verify the operation of safety valve attached to a sealed type lead-acid battery, which is the target.

A.11 Explosion-proof test

The test to verify explosion-proof performance of exhaust part.

A.12 Splash-proof test

The test to verify the amount of dilute sulphuric acid splashed out of the battery at charging.

A.13 Acceptance test, factory test

The acceptance test shall be agreed between the customer and the supplier. Compliance to marking and labeling or capacity rating may be checked.

Commissioning test

A.14 A commissioning test is recommended to prove the integrity of the installed battery system by means of a capacity test.