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IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems

Sponsor

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

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Abstract: Design considerations and procedures for storage, location, mounting, ventilation, assembly, and maintenance of lead-acid storage batteries for photovoltaic power systems are provided. Safety precautions and instrumentation considerations are also included. Even though general recommended practices are covered, battery manufacturers may provide specific instructions for battery installation and maintenance.
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Introduction

[This introduction is not part of IEEE Std 937-2000, IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems.]

This recommended practice provides design considerations and procedures for storage, location, mounting, ventilation, assembly, and maintainance of lead-acid storage batteries for photovoltaic power systems. Safety precautions and instrumentation considerations are also included. While this document gives general recommended practices, battery manufacturers may provide specific instructions for battery installation and maintenance.

While there are other IEEE standards that cover lead-acid battery installation and maintenance, they are generally designed for other types of applications, such as float-service, utility grid-tied applications. This document provides information for installation and maintenance of lead-acid batteries in photovoltaic applications that are characterized by nongrid connected, cycling service. These procedures also reflect consideration of the typically remote nature of photovoltaic applications.

The Storage Systems Working Group of the Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage (SCC21) that developed this recommended practice consisted of the following members:

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IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems

1. Overview

1.1 Scope

This recommended practice provides design considerations and procedures for storage, location, mounting, ventilation, assembly, and maintenance of lead-acid storage batteries for photovoltaic power systems. Safety precautions and instrumentation considerations are also included.

While this document gives general recommended practices, battery manufacturers may provide specific instructions for battery installation and maintenance.

1.2 Purpose

This recommended practice is meant to assist lead-acid battery users to properly store, install, and maintain lead-acid batteries used in residential, commercial, and industrial photovoltaic systems.

2. References

This recommended practice should be used in conjunction with the following publication. When the following standard is superseded by an approved revision, the revision should apply.

Accredited Standards Committee C2-1997, National Electrical Safety Code® (NESC®).[1]

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

3. Definitions

The following definitions apply specifically to this recommended practice. For other definitions, see The IEEE Standards Dictionary of Electrical and Electronics Terms [B6].[2]

3.1 capacity (C): Generally, the total number of ampere-hours that can be withdrawn from a fully charged battery at a specific discharge rate and electrolyte temperature, and to a specific cutoff voltage.

3.2 dry-charged cell: A cell that does not contain electrolyte for ease in shipping or storage, or both.

3.3 equalizing voltage: The voltage, higher than float, applied to a battery to correct inequalities among battery cells (voltage or specific gravity) that may develop in service.

3.4 freshening charge: The charging of batteries to assure that they are maintained "fresh" in a near-maximum state of charge, and to assure that there is no deterioration of the battery plates due to self-discharge and resulting sulfation. Freshening charges are usually performed using the manufacturer's recommended equalization or cycle-service charging voltage.

3.5 life: The period during which a fully charged battery is capable of delivering at least a specified percentage of its capacity, generally 80%.

3.6 pilot cell(s): One or more cells chosen for monitoring the operating parameters, e.g., cell voltage, specific gravity and temperature, of the entire battery.

3.7 valve-regulated lead-acid cell (VRLA): A lead-acid cell that is sealed, with the exception of a valve that opens to the atmosphere when the internal gas pressure in the cell exceeds the atmospheric pressure by a preselected amount. Valve-regulated cells provide a means for recombination of internally generated oxygen and the suppression of hydrogen gas evolution to limit water consumption.

3.8 vented cell: A cell in which the products of electrolysis and evaporation are allowed to escape to the atmosphere as they are generated. These batteries are commonly referred to as "flooded."

4. Safety

The safety practices listed herein should be followed during battery installation and maintenance. Work performed on batteries shall be done with the proper tools and protective equipment. Battery installation shall be performed or supervised by personnel knowledgeable of batteries and the required safety precautions. Keep unauthorized personnel away from batteries.

4.1 Protective equipment

The following equipment is recommended for safer handling of lead-acid batteries and protection of personnel:

a) Full eye protection, such as goggles or a face shield.
b) Protective clothing, including acid-resistant gloves, aprons, and overshoes.
c) Portable or stationary safety shower and eye-wash stations.
d) A suitable acid-neutralizing agent, such as bicarbonate of soda (baking soda).
e) A lifting device of adequate capacity.

[2]The numbers in brackets correspond to those of the bibliography in Annex B.

f) Tools with appropriately insulated handles.
g) A Class C fire extinguisher (CO_2-type extinguishers should not be used because of the potential thermal shock to batteries).

4.2 Safety procedures

The following are hazards inherent in the use of lead-acid batteries and the recommended related procedures to help ensure safety.

4.2.1 Electrolyte hazards

The electrolyte is a sulfuric-acid solution that is harmful to the skin and eyes. It is corrosive and electrically conductive. The following procedures should be followed when handling the battery and electrolyte:

a) Wear full eye protection and protective clothing.
b) If electrolyte contacts the skin, wash it off immediately with water.
c) If electrolyte contacts the eyes, immediately and thoroughly flush with water, then seek medical attention.
d) Spilled electrolyte should be neutralized. A common practice is to use a solution of approximately 500 g of bicarbonate of soda to approximately 4 L of water. The bicarbonate of soda solution should be added to the electrolyte until the evidence of reaction (foaming) has ceased.

   NOTE—The removal and/or neutralization of an acid spill may result in the production of a hazardous waste. The user should comply with the appropriate governmental regulations.

e) Properly dispose of unused electrolyte and electrolyte containers. These may be considered hazardous waste and should be treated accordingly.

4.2.2 Electrical hazards

A battery can present an electrical shock and short-circuit hazard. The following procedures should be followed to lessen the risk of electrical hazards:

a) Remove watches, rings, or other metal objects.
b) Wear rubber or plastic gloves and boots.
c) Use tools with insulated handles.
d) Disconnect the charging source and load prior to opening or closing any other battery connections.
e) Determine if the battery is inadvertently grounded and, if so, remove source(s) of ground (e.g., electrolyte spillage). Contact with any electrically conductive path of a grounded battery can result in electrical shock; the likelihood of shock can be reduced if inadvertent grounds are removed.

4.2.3 Fire hazards

Lead-acid batteries can present a fire hazard because they generate hydrogen gas and are capable of producing high current. The following procedures should be followed to lessen the risk of fire hazards:

a) Provide ventilation in accordance with item a) of 5.1.3.
b) Prohibit smoking in the battery area.
c) Keep the battery area free from open flames and arcs.
d) Discharge static electricity from body before touching batteries by first touching a grounded metal surface, such as a water pipe.

e) Use flame-arresting vents, if the cell design allows.
f) Maintain battery and connections in accordance with Clause 7.
g) Follow proper installation procedures (see Clause 6).
h) Use of any auxiliary devices, such as hydrogen recombiners or flame arresters, should be in strict accordance with the battery manufacturer's recommendations.

4.2.4 Handling hazards

The following safety procedures should be followed prior to and during installation of a battery:

a) Inspect all lifting devices for functional adequacy, and use properly.
b) In the case of rack mounting, completely assemble and tighten racks before loading cells, or load in accordance with manufacturer's recommendations.
c) Prevent impact of cells to avoid damage.
d) Ensure that all cell openings are capped.
e) Avoid excessive tilting of vented cells that could result in electrolyte spillage.

4.2.5 General

The following are general safety precautions:

a) Ensure unobstructed egress from the battery area.
b) Prevent unauthorized access to battery area.
c) Keep the top of the battery clear of all tools and other foreign objects at all times.

5. Installation design criteria

Considerations that should be included in the design of a photovoltaic battery installation depend upon the requirements, function, and size of the system of which the battery is a part. The following subclauses describe general criteria for all photovoltaic battery installations.

5.1 Enclosure

Batteries should be protected by means of a suitable enclosure, which may vary from a box to a room. The enclosure should be clean, dry, adequately ventilated, and provide and maintain protection against detrimental environmental conditions.

5.1.1 Location

The following should be considered when deciding on the location of the battery enclosure:

a) The battery enclosure should be located as close as practical to the photovoltaic array, loads, and power conditioning equipment, consistent with item d) of 5.3.
b) The enclosure location should provide adequate structural support and be as free of vibration as practical.
c) The battery location should preclude contamination of water supplies and damage to equipment in the event of electrolyte spillage.

5.1.2 Mechanical considerations

The following mechanical aspects should be considered during the design or selection of the battery enclosure:

a) The size of enclosure should allow for sufficient clearance around the battery to provide access for installation and maintenance. Consideration should be given to the space required for safety and handling equipment (see 4.1).
b) The supporting surface of the enclosure should have adequate structural strength to support the battery weight and its support structure.
c) The enclosure should be resistant to the effects of electrolyte, either by selection of materials used or by appropriate coatings. Provision should be made for containment of any spilled electrolyte per appropriate codes and regulations.
d) Any enclosure doors should allow unobstructed egress.
e) The enclosure design should include appropriate means to prevent unauthorized entry.

5.1.3 Environmental considerations

The following environmental aspects should be considered during the design or selection of the battery enclosure:

a) The enclosure shall be ventilated, either by natural or induced means, to prevent the accumulation of an explosive hydrogen mixture, and to limit the accumulation of other hazardous gases. The hydrogen concentration shall be limited to less than 2% by volume. The enclosure design should either avoid creation of difficult-to-ventilate areas, including false ceilings, or make adequate provision for their ventilation. Further, the enclosure should be designed so that flammable or hazardous gases vented from it cannot enter a heating, cooling, or ventilation system serving a habitable area.
b) To prevent battery damage, the enclosure should be designed to maintain the electrolyte temperature above its freezing point. The temperature at which the electrolyte will freeze for a given battery state of charge and operating-specific gravity may be obtained from the battery manufacturer. Extremely high electrolyte temperatures may cause excessive water usage and may damage the battery. Battery manufacturers may recommend a maximum operating temperature for their batteries.
c) A cell electrolyte temperature of 25 °C is normally the basis for rated performance. A location where this temperature can be maintained should contribute to optimum battery life. Either passive or active means to reduce temperature excursions from 25 °C should be considered. Passive means can include partial burial of enclosures, color of exterior finish, and insulation. Active means can include forced-air ventilation.

   NOTE—If the electrolyte temperature varies from optimum, sizing may be affected.
d) Temperature differences between cells within the battery should be limited to 3 °C. Localized heat sources, including direct sunlight, radiators, steam pipes, and space heaters, should be avoided.
e) Illumination of enclosures during time of maintenance should be adequate for the safety and effectiveness of personnel.

5.2 Battery support structure

Battery support structures may consist of racks or other means for supporting the battery within the enclosure. Battery support structures should have the following design features:

a) Provide suitable strength to support the battery.
b) Minimize temperature differentials [see item c) of 5.1.3].

c) Provide space required for maintenance [see item a) 5.1.2].
d) Be resistant to the effects of electrolyte.
e) Provide electrical isolation for the cell case and battery. Any insulating material used should be rated for full system voltage.
f) Provide space between the cells for air circulation.

5.3 Electrical

Electrical installations should be in accordance with appropriate electrical codes and regulations [such as the National Electric Safety Code® (NESC®) (Accredited Standards Committee C2-1997)].[3]

a) Considerations should be given to insulating bare terminals, lugs, fittings, and other live parts to reduce the risk of fire, and shock and burns to personnel.
b) Electrical cabling to the battery should be designed so that it does not obstruct access space provided for maintenance and safety, nor result in undue stress to battery terminals.
c) All battery systems should be provided with overcurrent protection and disconnecting means. This also applies to all potential current-carrying instrumentation and control leads connected to the battery system.
d) Systems that are grounded should be grounded according to appropriate codes.
e) Equipment with arcing contacts should be located to avoid battery enclosure areas where explosive hydrogen concentrations could occur.
f) Consideration should be given to providing essential instrumentation and alarm functions, if not provided by the charging control. These include
    1) Voltmeter
    2) Ammeter
    3) High- and low-voltage indicators
    4) Ground fault detector(s)
    5) Temperature sensor(s)

5.4 Seismic

When a photovoltaic system is installed in a a location subject to a high probability of seismic disturbance, the batteries should be designed and installed in a manner that resists damage from seismic events, and in accordance with appropriate codes and regulations.

6. Installation procedures[4]

6.1 Receiving and storage

6.1.1 Receiving inspection

The following should be considered when receiving shipment of a battery:

a) Upon receipt, inspect the shipment for damage that might have occurred in transit.
b) Take notice of the shipping date. Timely unpacking may be required in order to follow the manufacturer's recommendation on the freshening charge.

[3]Information on references can be found in Clause 2.
[4]For safety precautions, refer to Clause 4.

6.1.2 Unpacking

Batteries are typically shipped either securely banded to wood pallets or as modular units. System accessories may be packed separately. To move pallets or modules, use material handling equipment adequate for the weight. Do not impact, tip, or drop batteries as damage may result. In addition

a) Carefully cut the banding and remove protective packaging materials from the top and sides of the batteries. If additional transportation to a remote location is required, attempt to transport individual batteries with as much of the original packing material as possible.
b) After unpacking the batteries, inspect for damage. All damaged batteries should be repaired or replaced.
c) Where possible, for vented cells check electrolyte levels to determine that the plates are covered. The battery/cell may require replacement if the electrolyte level is below the top of the plates.
d) Always lift batteries according to the manufacturer's instructions.

6.1.3 Storage

It is recommended that the site construction allow for scheduling battery installation shortly after receipt. If battery storage is required, the following practices should be followed:

a) Batteries should be stored indoors in a clean, cool, and dry area. Temperature extremes and localized heat sources, such as radiators or direct sunlight, should be avoided.
b) Do not double-stack pallets, or store anything on top of the batteries, as damage may result.
c) Batteries should not be stored for more than the time period recommended by the manufacturer without applying a freshening charge. This charge should be applied in accordance with the manufacturer's recommendations.
d) Record dates and battery conditions for all charges during storage.

6.2 Battery support structure assembly

The assembly of the support structure should be in accordance with the manufacturer's recommended procedures.

6.3 Battery mounting and connections

Various methods of interconnecting batteries are used. The following procedures generally apply to all methods of interconnection, but individual steps may be modified per the manufacturer's instructions.

NOTE—Dry-charged batteries may be mounted either before or after the addition of electrolyte. It is recommended that intercell connectors be installed after addition of electrolyte.

a) For multilevel support structures, it is important to maintain stability during installation. It is generally recommended that batteries be placed onto the support structure starting at the center of the lowest level, and working outward and upward while maintaining the recommended spacing. Do not slide batteries across rough surfaces, nor lubricate the bottom surface of the battery to aid sliding, as case damage may occur.
b) The battery terminals may be shipped with a coating of corrosion-inhibiting grease. Clean any area showing evidence of corrosion, dirt, or acid. Use only cleaning agents recommended by the manufacturer. Recoat the cleaned area with a thin film of a corrosion-inhibiting grease recommended by the manufacturer.
c) If used, install flame-arresting vent assemblies to reduce the risk of explosion.

d) Measure the voltage of each cell/battery, and correct discrepancies as required.

e) Connector surfaces should be cleaned by rubbing them gently with a brass suede brush. Care should be exercised in cleaning to prevent removal of the lead plating. If recommended, apply a thin film of the corrosion-inhibiting grease to all contacting surfaces.

f) Interconnect batteries so as to make series, parallel, or series-parallel connections in accordance with the following considerations:
   1) When more than one connector per terminal is required, mount the connectors on opposite sides of terminal for maximum surface contact.
   2) Cables should be prebent prior to connection to reduce stress on terminals.
   3) In general, all series connections should be made prior to parallel connections.
   4) Verify the correct polarity of each cell/battery by measuring the overall string voltage. This should be equal to the voltage of each unit multiplied by the number of units.

g) With the batteries properly aligned, tighten connections (including factory-made connections) to the battery manufacturer's recommended torque value.

h) Where required, install any auxiliary components.

i) For future identification, apply individual cell numbers in sequence (beginning with number one) at the positive end of the battery. Also add any required operating identification.

6.4 Preoperational checks

The following preoperational checks should be performed during battery installation:

a) It is advisable to measure and record interbattery connection resistances to determine the adequacy of the initial installation, and as a reference for future maintenance requirements. Remake and remeasure any connection that has a resistance significantly above the average.

b) Clean all cell covers and containers. To remove dust and dirt, use a water-moistened clean wiper. To clean electrolyte spillage, use a wiper moistened with a solution of bicarbonate of soda and water. All wipers should be free of oil distillates or solvents that may cause damage to the container or contaminate the electrolyte.

c) Perform a visual inspection of completed battery installation to verify the following:
   1) Correct assembly in accordance with electrical and mechanical specifications.
   2) Integrity of all components.
   3) Cleanliness and performance of all work in accordance with good workmanship practices.

6.5 Initial charging procedure

It is desirable to perform an initial charge to bring the battery to a fully charged condition, and to ensure all cells are equally charged. Dry-charged batteries must be activated prior to performing this procedure (see Annex A).

NOTES

1—Field conditions may prevent strict adherence to the following procedure.

2—The system load should not be connected at this time.

The preferred method is to charge the battery at a constant voltage. This should be done in accordance with the manufacturer's recommendation. The charging current should not exceed the limit as specified by the manufacturer or as limited by auxiliary devices, such as hydrogen recombiners or flame arresters. Unless otherwise specified, if any cell temperature exceeds 43 °C, interrupt or reduce the charge until the temperature has dropped to 38 °C, at which time charging may be resumed. See the battery manufacturer's recommendations for more information.

The charge is complete and the battery is fully charged when the cell voltages and the charging current have not changed in three consecutive hours. The state of charge can be estimated by taking measurements of the terminal voltages and charging current, and by using charging curves available from the manufacturer. The specific gravity of vented cells may be used to estimate the cell's state of charge; however, this method depends on additional factors. If the specific gravity is out of the manufacturer's recommended range after stable cell voltages and currents have been achieved, refer to the manufacturer's instructions for corrective actions.

If necessary for vented cells, add water of the quality and quantity specified by the manufacturer at the completion of the initial charging procedure.

NOTE—Dry-charged cell electrolyte levels should be adjusted using electrolyte of the specified specific gravity.

6.6 Final connections

When all installation procedures have been satisfied, complete the system connections.

7. Maintenance

7.1 General

Proper maintenance should prolong the life of a battery and help assure that it is capable of satisfying design requirements. A good battery maintenance program should serve as a valuable aid in determining the need for battery replacement. Only personnel who are familiar with battery installation, charging, and maintenance procedures should be permitted access to the battery area. The safety practices of Clause 4 should be followed.

7.2 Inspections

The results of all inspections should be recorded. Adequate battery records (previous maintenance procedures, environmental problems, system failures, and any corrective actions taken in the past) are invaluable aids in determining battery conditions.

It is preferable that all inspections be made on a fully charged battery. The following inspection schedule is recommended for good maintenance; however, certain cell designs may preclude performance of some of the inspections listed.

7.2.1 Initial readings

The initial readings are those readings taken at the time the battery is placed in service. The following readings should be taken and recorded on a fully charged battery with no load on the system:

a) Battery terminal voltage and cell voltages (preferably, these voltages should be taken with the battery on charge; charging current should also be recorded).
b) Cell electrolyte levels, where appropriate.
c) Internal temperatures of at least 10% of the cells (for valve-regulated batteries, the temperature of the negative terminal post should be read).

d) Ambient temperature.
e) Specific gravity reading of each cell corrected to 25 °C, where applicable.

It is important that these initial readings be retained for future comparison.

7.2.2 Monthly

Perform the following inspections on a monthly basis:

a) General appearance and cleanliness of the battery and battery area.
b) Battery terminal voltage and charging current (whenever possible). If possible, these measurements should be made when the battery is fully charged.
c) Electrolyte levels, where applicable.
d) Cracks in battery cases or leakage of electrolyte.
e) Evidence of corrosion at connections.
f) Ambient temperature.
g) Condition of ventilation system.
h) Pilot-cell (if used) voltage, specific gravity, and electrolyte temperature (whenever possible).
i) Evidence of current leakage to ground.

7.2.3 Quarterly

In addition to the monthly items, inspect the following every three months:

a) Battery terminal voltage and cell voltages. If possible, these measurements should be made when the battery is fully charged.
b) Specific gravity of each cell corrected to 25 °C (whenever possible).
c) Internal temperature of at least 10% of the cells.

7.2.4 Annually

In addition to the quarterly items, inspect the following once a year:

a) Tightness of all bolted connections (torque specified by manufacturer).
b) Integrity of battery support structure and enclosure.

7.2.5 Special inspections

If the battery has experienced an abnormal condition (such as a severe discharge, overcharge, or unanticipated temperature excursion), an inspection should be made to determine if the battery has been damaged. This inspection should include the requirements of 7.2.3, plus a detailed visual inspection of each cell.

7.3 Corrective actions

The following items are conditions that, if discovered, should be corrected at the time of inspection:

a) For vented cells, correct low electrolyte levels and record the amount of water added. Enough water should be added to bring all cells to the high-level line. Water quality should be in accordance with the manufacturer's instructions. To avoid electrolyte overflow, water should be added only when it has been determined that the cells are in a fully charged condition.

NOTE—The addition of water will alter the specific gravity of the electrolyte, and additional charging will be required for mixing.

b) Clean corroded connections (high-connection resistances) by disassembling, cleaning, and reassembling them. Then tighten all bolted connections to the torque specified by manufacturer.
c) When cell temperatures deviate more than to 3 °C from each other during a single inspection, determine the cause and correct, if practical.
d) If a battery temperature outside the system design limits is noted, determine the cause and correct, if practical.
e) Remove excessive dirt or spilled electrolyte in accordance with item c) of 6.4.
f) When the fully charged battery voltage is outside the manufacturer's recommended range, the cause should be determined and corrected.
g) Any other abnormal condition should be corrected per the manufacturer's recommendations.

The corrective action of an equalizing charge, performed in accordance with the manufacturer's instructions, is indicated whenever any of the following conditions are found. These conditions, if allowed to persist for extended periods, can reduce battery life. They do not necessarily indicate a loss of capacity.

— For vented cells, the specific gravity, corrected for temperature and electrolyte level, of an individual cell is more than 10 points (0.010) below the average of all cells at the time of inspection.
— For vented cells, the average specific gravity, corrected for temperature and electrolyte levels, of all cells drops more than 10 points (0.010) from the average installation value (see 7.2.1) when the battery is fully charged.
— The fully charged cell voltage is 0.1 V outside of the manufacturer's recommended end-of-charge cell voltage.

CAUTION: The equalizing voltage may present a hazard to other connected equipment.

8. Recycling and disposal

All batteries have a useful life and eventually must be either disposed of or recycled.

8.1 Recycling

Lead-acid batteries can be fully recycled. Seek advice from the battery manufacturer on how to proceed with battery recycling.

8.2 Disposal

When a battery is to be disposed of, governmental regulations for such disposal shall be followed. The local hazardous waste management agency can give information on how to proceed with respect to applicable regulations.

Annex A

(informative)

Activation of dry-charged cells

Dry-charged cells should be activated (filled with electrolyte and charged) when they are ready to be placed in service.

When the battery charging source is fully functional, remove the shipping plug/caps from the cells and fill batteries to be activated to the low-level line, or to the level specified by the manufacturer, with the supplied or approved grade of electrolyte. Electrolyte should be agitated to eliminate stratification prior to introduction into cells.

NOTE—It is the responsibility of the user to neutralize and dispose of any excess electrolyte. It is strongly recommended that the user neutralize and render useless all containers in which the acid was supplied so as to preclude the possibility of accidental poisoning or injury through the use of the containers for food or liquid. Follow appropriate governmental regulations.

Allow the battery to stand a minimum of 4 h after filling, then add sufficient electrolyte to bring the electrolyte level up to the manufacturer's recommended level. The initial charge should be started within 16 h of initial battery filling, and in accordance with the charging rate and duration specified by the manufacturer.

Annex B

(informative)

Bibliography

[B1] IEEE Std 450-1995, IEEE Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

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