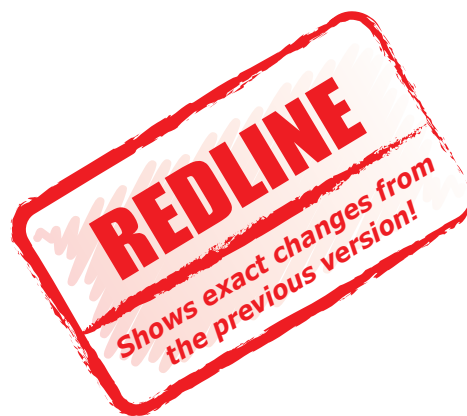


IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications

IEEE Power & Energy Society

Sponsored by the
Stationary Batteries Committee



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IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications

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Stationary Batteries Committee
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IEEE Power & Energy Society

Approved 9 December 2010

IEEE-SA Standards Board

Abstract: Maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of permanently installed, vented lead-acid storage batteries used for standby service are provided. This recommended practice also provides guidance to determine when batteries should be replaced. This recommended practice is applicable to standby service stationary applications where a charger maintains the battery fully charged and supplies the dc loads.

Keywords: acceptance test, battery capacity, battery installation, battery maintenance, battery replacement criteria, battery service test, battery terminal voltage, connection resistance measurements, electrolyte level, equalize charge, float voltage, IEEE 450, modified performance test, performance test, service test, specific gravity, standby power applications, state of charge, test-discharge rate, vented lead-acid battery

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Introduction

This introduction is not part of IEEE Std 450-2010, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications.

Stationary lead-acid batteries play an ever-increasing role in industry today by providing normal control and instrumentation power and back-up energy for emergencies. This recommended practice fulfills the need within the industry to provide common or standard practices for battery maintenance, testing, and replacement. The installations considered herein are designed for standby service with a battery charger serving to maintain the battery in a charged condition as well as to supply power to the normal dc loads. However, specific applications, such as emergency lighting units and semi-portable equipment, may have other appropriate practices that are beyond the scope of this recommended practice.

This recommended practice may be used separately, and, when combined with IEEE Std 484™, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications and IEEE Std 485™, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications, will provide the user with a general guide to sizing, designing, placing in service, maintaining, and testing a vented lead-acid storage battery installation. IEEE Std 535 provides a standard for qualification of Class 1E lead storage batteries for nuclear power generating stations.

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1. Overview

1.1 Scope

This document provides recommended maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of permanently-installed, vented lead-acid storage batteries used in standby ~~power applications~~ service. It also provides guidance to determine when batteries should be replaced. This recommended practice is applicable to ~~full float~~ standby service stationary applications where a battery charger normally maintains the battery fully charged and provides the dc loads. ~~However, specific applications, such as emergency lighting units and semi-portable equipment, may have other appropriate practices that are beyond the scope of this recommended practice.~~

~~Sizing, installation, qualification, other battery types, and application are also beyond the scope of this recommended practice.~~ The maintenance and testing programs described in this recommended practice represent “the best program” based on the information available at the time this document was developed. The user should evaluate these practices against their operating experience, operating conditions, manufacturer’s recommendations, resources, and needs in developing a maintenance program for a given application. These maintenance and testing recommendations were developed without consideration of economics, availability of testing equipment and personnel, or relative importance of the application. Development of a maintenance and testing program for a specific application requires consideration of all issues, not just the technical issues considered in this document.

1.2 Purpose

The purpose of this recommended practice is to provide the user with information and recommendations concerning the maintenance, testing, and replacement of vented lead-acid batteries used in stationary applications.

1.3 Exclusions

Specific applications, such as emergency lighting units, photovoltaic, cycling, and semi-portable equipment, may have other appropriate practices that are beyond the scope of this recommended practice. Sizing, installation, qualification, other battery types, and application are also beyond the scope of this recommended practice.

This recommended practice does not include any other component of the dc system, or inspection and testing of the dc system, even though the battery is part of that system. Pre-operational and periodic dc system tests of chargers and other dc components may require that the battery be connected to the system. Details for these tests depend on the requirements of the dc system and are beyond the scope of this recommended practice.

1.4 Document Organization

This recommended practice is divided into twelve clauses. Clause 1 provides the scope of this recommended practice. Clause 2 lists references to other standards that are useful in applying this recommended practice. Clause 3 provides definitions that are either not found in other standards, or have been modified for use with this recommended practice. Clause 4 establishes the safety precautions to be followed during battery maintenance and testing. Clause 5 describes the recommended maintenance practices. Clause 6 establishes the recommended testing program. Clause 7 establishes the types and methodology for battery testing. Clause 8 establishes battery replacement criteria. Clause 9 describes the records to be maintained. Clause 10 provides guidance on trending of battery parameters. Clause 11 describes recycling and disposal of vented lead-acid batteries. Clause 12 describes spill containment management.

This recommended practice has thirteen annexes. Annex A discusses state of charge. Annex B discusses specific-gravity measurements. Annex C provides information on float voltage. Annex D provides information on the urgency of corrective actions for discrepancies found during maintenance and testing. Annex E describes the visual inspection requirements. Annex F provides methods for measuring connection resistances. Annex G discusses alternative test and inspection programs. Annex H describes the effects of elevated temperature on lead-acid batteries. Annex I provides methodologies for conducting a modified performance test. Annex J provides information on internal ohmic measurements. Annex K provides methods for calculation of battery capacity. Annex L provides temperature-correction factors in degrees Fahrenheit. Annex M provides bibliographic references.

2. Normative references

~~This recommended practice shall be used in conjunction with the following publications:~~The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 484TM~~-1996~~, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications (ANSI/BCI).¹²

IEEE Std 485TM~~-1997~~, IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications (BCI).

IEEE Std. 1491TM, IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications.

IEEE Std. 1578TM, IEEE Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. *The IEEE Standards Dictionary: Glossary of Terms & Definitions* should be consulted for terms not defined in this clause.³

acceptance test: A ~~constant-current or constant-power~~ capacity test made on a new battery to determine if it meets specifications or manufacturer's ratings.

capacity test: A controlled constant-current or constant-power discharge of a battery to a specified terminal voltage.

critical period: That portion of the duty cycle that is the most severe, or the specified time period of the battery duty cycle that is most severe.

duty cycle: The sequence of loads a battery is expected to supply for specified time periods ~~while maintaining a minimum specified voltage.~~

~~equalizing voltage: The voltage, charge: A charge, at a level higher than float~~ the normal float voltage, applied to a battery for a limited period of time, to correct inequalities among battery cells (voltage or specific gravity, or state of charge that may have developed between the cells during normal operation service.

~~3.7 flooded 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 also referred to as "vented."~~

equalizing voltage: The voltage at which an equalizing charge is performed.

~~3.8 modified float charge:~~ A constant-potential charge applied to a battery to maintain it in a fully charged condition while minimizing degradation or water consumption.

float current: The current flowing during a float charge.

float voltage: The voltage applied to a battery during a float charge.

modified performance test: A test, in the "as found" condition, of battery capacity and the ability of the battery to satisfy the duty cycle.

¹ IEEE publications are 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/>). ~~and <<http://standards.ieee.org/sds/index.html>>~~

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³ *The IEEE Standards Dictionary: Glossary of Terms & Definitions* is available at <http://shop.ieee.org/>.

performance test: A constant-current or constant-power capacity test made on a battery after it has been in service, ~~to detect any change in the capacity.~~

polarization: The shift in the potential of an electrode, or the voltage of a cell/battery, from the open-circuit value, brought about by the flow of current.

rated capacity (lead-acid): The capacity assigned to a cell by its manufacturer for a given discharge rate, at a specified electrolyte temperature and specific gravity, to a given end-of-discharge voltage.

service test: A test of a battery's capability, in an "as-found" condition, to satisfy the battery duty cycle.

terminal connection: Connections made between cells or at the positive and negative terminals of the battery, which may include terminal plates, cables with lugs, and connectors.

vented cell: A cell in which the products of electrolysis and evaporation are allowed to escape into the atmosphere as they are generated (sometimes also referred to as “flooded”).

3.2 Abbreviations

S.G. specific gravity

MPT modified performance test

4. Safety

WARNING

BATTERIES ARE POTENTIALLY DANGEROUS AND PROPER PRECAUTIONS MUST BE OBSERVED IN ALL BATTERY HANDLING AND MAINTENANCE. WORK ON BATTERIES SHALL BE PERFORMED ONLY WITH PROPER TOOLS AND SHALL UTILIZE THE PROTECTIVE EQUIPMENT LISTED. BATTERY MAINTENANCE SHALL BE PERFORMED BY PERSONNEL KNOWLEDGEABLE OF BATTERIES AND TRAINED IN THE SAFETY PRECAUTIONS INVOLVED.

4.1 Protective equipment

The following protective equipment shall be worn by personnel who perform battery maintenance work or made available to such personnel:

- a) Goggles and face shields
- b) Acid-resistant gloves
- c) Protective aprons
- d) Portable or stationary water facilities for rinsing eyes and skin in case of contact with electrolyte
- e) Bicarbonate of soda solution, mixed 100 grams bicarbonate of soda to 1 liter of water, to neutralize acid spillage

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

- f) Class C fire extinguisher

NOTE—Some battery manufacturers do not recommend the use of CO₂ Class C fire extinguishers due to the potential of thermal shock.

- g) Adequately insulated tools
- h) Barriers to prevent the spread of acid spills are extremely important when moving cells such as during battery installation or removal activities. See IEEE Std 1578⁴ for information on barriers.

4.2 Precautions

The following protective procedures shall be observed during maintenance:

- a) Use caution when working on batteries since they represent a shock hazard.
- b) Prohibit smoking and open flames, and avoid activities that increase the chances of arcing in the immediate vicinity of the battery.
- c) Verify that the load test leads are clean, in good condition, and connected with sufficient length of cable to minimize the risk of accidental arcing in the vicinity of the battery.
- d) Verify that all connections to load test equipment include appropriate short-circuit protection.
- e) Verify that battery area ventilation is operating per its design.
- f) Verify unobstructed egress from the battery area.
- g) Avoid the wearing of metallic objects such as jewelry.
- h) Neutralize static buildup just before working on the battery by contacting the nearest effectively grounded surface.
- i) If installed, verify that the battery monitoring system is operational.

4.3 Methods

Work performed on an in-service battery shall use methods that preclude circuit interruption or arcing in the vicinity of the battery.

5. Maintenance

5.1 General

Proper maintenance will prolong the life of a battery and will help enable the battery to satisfy its design requirements. A good battery maintenance program will serve as a valuable aid in maximizing battery life, preventing avoidable failures, and reducing premature replacement. Personnel knowledgeable of batteries and the safety precautions involved shall perform battery maintenance.

⁴ [Information on references can be found in Clause 2.](#)

(See IEEE Std 484 for initial installation requirements.)

5.2 Inspections

~~Implementation of~~ Periodic inspections provide the user with information for determining the condition of the battery. The frequency of the inspections should be based on the nature of the application and may exceed that recommended herein. All inspections should be made under normal float conditions. For specific-gravity measurements to be meaningful, the electrolyte must be fully mixed. Electrolyte mixing is unlikely to exist following a recharge or water addition. Measurements should be taken in accordance with the manufacturer's instructions. Refer to the annexes for more information.

5.2.1 Monthly

Inspection of the battery on a regularly scheduled basis (at least once per month) should include a check and record of the following:

- a) Float voltage measured at the battery terminals
- b) General appearance and cleanliness of the battery, battery rack or battery cabinet, and the battery area
- c) Charger output current and voltage
- d) Electrolyte levels
- e) Cracks in cells or evidence of electrolyte leakage
- f) Any evidence of corrosion at terminals, connectors, racks, or cabinets
- g) Ambient temperature and ventilation
- h) Pilot cells (if used) voltage and electrolyte temperature
- i) Battery float charging current or pilot cell specific gravity ([For lead-antimony cells, specific gravity is preferred. Contact the manufacturer for specific recommendations.](#)) (see 5.4)
- j) Unintentional battery grounds
- k) All battery monitoring systems are operational (if installed)

5.2.2 Quarterly

At least once per quarter, a monthly inspection should be augmented as follows. Check and record the following:

- a) Voltage of each cell
- b) [For lead-antimony batteries,](#) specific gravity of 10% of the cells of the battery ([see 5.4.2](#)) and float charging current
- c) [For technologies other than lead-antimony,](#) if battery float charging current is not used to monitor state of charge
- ~~e) Electrolyte temperature of, [specific gravity of 10% or more of the cells](#) of the battery ([see 5.4.2](#))~~
- d) [Temperature of a representative sample of 10% of the battery cells \(Example for a sixty cell string, measure the temperature of every tenth cell for a total of six cells.\)](#)

5.2.3 Yearly

At least once each year, the quarterly inspection should be augmented as follows. Check and record the following:

- a) [For lead-antimony batteries,](#) specific gravity ~~and temperature~~ of [all cells of the battery](#) ([see 5.4.2](#))
- b) [For technologies other than lead-antimony, if battery float charging current is not used to monitor state of charge, specific gravity of all cells of the battery](#) ([see 5.4.2](#))
- c) Cell condition [This involves a detailed visual inspection (see Annex E for guidelines) of each cell in contrast to the monthly inspection in 5.2.1. Review manufacturer's recommendations.]
- d) Cell-to-cell and terminal connection resistance (see Annex F)
- e) Structural integrity of the battery rack and/or cabinet ([see Annex E](#))

5.2.4 Special inspections

[A complete set of specific-gravity readings should be recorded upon initial installation and after two years of service on all cell types.](#)

If the battery has experienced an abnormal condition ~~(such as a severe discharge or overcharge)~~, an inspection should be made to verify that the battery has not been damaged. Include the requirements of 5.2.1, 5.2.2, and 5.2.3. [Contact the battery manufacturer for assistance.](#)

5.2.5 Monitoring

[Battery monitoring can be used to enhance data collection, trending \(see Clause 10\), and to store a record of battery system parameters. Battery monitoring can also provide remote visibility and alert personnel of impending problems. However, monitoring is not a substitute for periodic visual inspections per 5.2.3 or conducting discharge tests at the frequency defined in Clause 6. See IEEE 1491, "IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications."](#)

5.3 Corrective actions

The corrective actions listed in 5.3.1 through 5.3.3 are meant to provide optimum life of the battery. However, the corrective actions in themselves will not guarantee that the battery is completely charged at any given time. Annex A through Annex G provide some technical background for the recommended actions and their timing, and provide other methods for determining the state of charge of a battery.

5.3.1 Cell/battery problems

The following items indicate conditions that can be easily corrected prior to the next monthly inspection. Major deviations in any of these items may necessitate immediate action.

- a) When any cell electrolyte reaches the low-level line, distilled or other approved-quality water should be added to bring the cells to the manufacturer's recommended full level line. Water quality should be in accordance with the manufacturer's instructions.
- b) If [post or terminal](#) corrosion is noted, remove the visible corrosion and check the resistance of the connection.
- c) If resistance measurements obtained in 5.2.3, item d) or 5.3.1, item b) are more than 20% above the installation value or above a ceiling value established by the manufacturer/system designer, or if loose connections are noted, retorque and retest. If retested resistance value remains unacceptable, the connection should be disassembled, cleaned, reassembled, and retested. Refer to IEEE Std 484 for detailed procedures. See also D.2 and Annex F.
- d) When cell temperatures deviate more than 3 °C from each other during a single inspection, determine the cause and correct the problem. If sufficient correction cannot be made, contact the manufacturer for allowances that must be taken.

NOTE—When working with large multi-tier installations, the 3°C allowable deviation may not be achievable. The user should contact the manufacturer for guidance.

- e) When excessive dirt is noted on cells or connectors, remove it with a water-moistened clean wipe. Remove electrolyte spillage on cell covers and containers with a bicarbonate of soda solution mixed 100 grams of soda to 1 liter of water. Avoid the use of hydrocarbon-type cleaning agents (oil distillates) and strong alkaline cleaning agents, which may cause containers and covers to crack or craze.
- f) When the float voltage measured at the battery terminals is outside of its recommended operating range, it should be adjusted.

5.3.2 Equalizing charge

Item a) though item d) in this sub-clause indicate conditions that, if allowed to persist for extended periods, can reduce battery life. They do not necessarily indicate a loss of capacity. Therefore, the corrective action can be accomplished prior to the next quarterly inspection, provided that the battery condition is monitored at regular intervals (not to exceed one week). Note that an equalizing charge normally requires that equalizing voltage be applied continuously for 24 hours or longer. (Refer to the manufacturer's instructions.) Single cell charging is an acceptable method when a single cell or a small number of cells appear to need equalizing.

- a) An equalizing charge is desirable; if individual cell float voltage(s) deviate from the average value by an amount greater than that recommended by the manufacturer. ~~Typical recommendations are ± 0.05 V for lead-calcium cells and ± 0.03 V for lead-antimony cells.~~
- b) If an undercharge condition is suspected (low individual cell voltage, plate sulfation, etc.), specific-gravity readings should be taken on the suspect cells, especially if the cells are lead-antimony type. An equalizing charge should be given if the specific gravity, corrected for temperature, of an individual cell falls below the manufacturer's lower limit (see D.4).
- c) An equalizing charge should be given immediately if any cell voltage is below the manufacturer's recommended minimum cell voltage (see C.1).
- d) Some manufacturers recommend periodic equalizing charges. This equalizing charge can be waived for certain batteries based on an analysis of the records of operation and maintenance inspections (see 9).

5.3.3 Other abnormalities

Correct any other abnormal conditions noted. See Annex D for a more detailed discussion of these abnormalities and the urgency of the corrective actions.

5.4 State of charge

A fully-charged battery provides for maximum battery capacity. The charge returned to the battery under constant-voltage charging is linear while the charger is operating in current limit mode, and exponentially related to time when the charger comes out of current limit. The charge returned may also be affected by the charging voltage and the electrolyte temperature. Once charged, the ability of a battery to remain fully charged under float conditions is affected by the float voltage level and the electrolyte temperature. The type of cell may affect the choice of which indicator(s) to use as a measure of state of charge (see A.4).

5.4.1 State of charge indicator

The following may be used as indicators of return to a fully charged state after a discharge (see Annex A):

- a) Stabilized charging current when measured at the manufacturer's recommended voltage and temperature for recharging the battery.
- b) Verifying that the ampere hours returned to the battery are greater than the ampere hours removed plus the charging losses.

5.4.2 Specific-gravity indicator

Specific-gravity (S.G.) readings are not recommended to be taken on a regular basis with a few exceptions (see 5.2). If an undercharge condition is suspected (low voltage cells, plate sulfation, etc.), specific-gravity readings should be taken on the suspect cells, especially if the cells are lead-antimony type. Specific gravity may be used as an approximate indicator of full charge if the electrolyte density is sufficiently uniform through the cell (see Annex A and Annex B). Specific-gravity measurements are not as accurate for the first few weeks after a battery:

↓ [Has been recharged](#)

↓ [Has had an equalizing](#) charge

↓ Has had water added

~~When cell design permits, specific gravity measurement accuracy can be improved by averaging several measurements taken at different levels within a cell. If cell design does not permit several measurements at different levels, then a single measurement taken as close to mid-level as possible is the best option.~~

5.4.3 Charging [\(float\)](#) current indicator

5.4.3.1 Description

After the battery has been charged, stabilized charging (float) current may be used as an indicator that the battery is fully charged (see Annex A).

[Float current measurements can provide users with useful information related to the state of health of the battery. These measurements can also be used to indicate the operation of the charger and/or the integrity of the cell connections.](#)

5.4.3.2 Indications and interpretations

[With a constant-voltage charger, the charge current should decrease to a stable value as the battery becomes charged.](#)

[The float current of a fully charged battery will depend on the temperature, voltage, and condition of the battery; but a significant change in float current may indicate a need for more investigation. Contact the battery manufacturer for normal float current ranges.](#)

[Changes in the float current may indicate malfunctions in the charging or the battery system. The absence of float current may indicate charging system failure or an open circuit in the battery string.](#)

[A high float current may indicate failing cells present in the battery string, an elevated charger voltage setting, a ground fault, high battery temperature, or contaminated electrolyte. Float current can be measured by using a battery shunt or by using a clamp-on current sensor.](#)

[In lead-calcium and pure lead designs, a rising trend of the float current may indicate potential thermal runaway, undercharged cells, charger system malfunction, or degradation of the battery. In lead-antimony, an increase of four times the initial charging current and a doubling of the initial charging current in low-antimony cells may indicate similar conditions and should be investigated.](#)

6. Test schedule

6.1 General

The schedule of tests listed in 6.2 through 6.5 is used to:

- Determine whether the battery meets its specification, or the manufacturer's rating, or both.
- Periodically determine whether the performance of the battery is within acceptable limits.
- If required, determine whether the battery, as found, meets the design requirements of the system to which it is connected.