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(Revision of IEEE Std 450-1995)

# 450™

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

**IEEE Power Engineering Society**

Sponsored by the  
PES Stationary Battery Committee



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**PES Stationary Battery Committee**  
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**IEEE Power Engineering Society**

Approved 9 December 2002

**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 power applications are provided. This recommended practice also provides guidance to determine when batteries should be replaced. This recommended practice is applicable to full-float 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, 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 450-2002, IEEE Recommend 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 full-float operation 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™-1996, IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations and IEEE Std 485™-1997, IEEE Recommended Practice for Sizing Vented Lead-Acid Storage 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™-1986 provides a standard for qualification of Class 1E lead storage batteries for nuclear power generating stations.

## Participants

This recommended practice was prepared by the IEEE Standard 450 Working Group, Maintenance, and Testing Subcommittee of the Standards Coordinating Committee 29—PES Stationary Battery Committee. At the time this recommended practice was approved, the members of the IEEE Standard 450 Working Group were as follows:

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Robert R. Beavers  
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Thomas C. Gorlitz

Richard A. Greco  
Wayne E. Johnson  
Harold Kelly, Jr.  
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Jeffrey J. LaMarca  
Daniel S. Levin  
Louis Mallavarapu  
Jose A. Marrero  
James McDowall  
Kimberly Mosley  
Zbigniew Noworolski  
Bansi P. Patel

Manahar A. Patel  
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Saba N. Saba  
Amiya Samanta  
Sam Shah  
Witold Sokolski  
Frank L. Tarantino  
Harold Taylor  
Shawn I. Tyler  
Kurt W. Uhler  
Walter A. Wylie

The following members of the balloting committee voted on this standard. Balloters may have voted for approval, disapproval, or abstention.

James Anderson  
Curtis Ashton  
Gary Balash  
Farouk Baxter  
Robert R. Beavers  
Richard T. Bolgeo  
John Coyle  
William P. Cantor  
John Carter  
Jay L. Chamberlin  
Mark Clark  
Garth Corey  
Eddie Davis  
James Edmonds

Harold Epstein  
Robert Fletcher  
Jerry C. Gordon  
Thomas C. Gorlitz  
Randall Groves  
Paul Hellen  
Paul Johnson  
Roger Johnson  
Wayne E. Johnson  
Jeffrey J. LaMarca  
Alan Lamb  
Peter E. Langan  
Daniel S. Levin  
Joel Long  
Jose A. Marrero

Thomas McCaffrey  
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Bansi P. Patel  
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# IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications

## 1. Overview

### 1.1 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.

### 1.2 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 for standby power applications. It also provides guidance to determine when batteries should be replaced. This recommended practice is applicable to full-float 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.

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.

This recommended practice is divided into ten 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 describes recycling and disposal of vented lead-acid batteries.

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. References

This recommended practice shall be used in conjunction with the following publications:

IEEE Std 484™-1996, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications (ANSI/BCI).<sup>1,2</sup>

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

## 3. Definitions

For purposes of this recommended practice the following terms and definitions apply. IEEE 100 [B1] should be referenced for terms not defined in this clause.

**3.1 acceptance test:** A constant-current or constant-power capacity test made on a new battery to confirm that it meets specifications or manufacturer's ratings.

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

**3.3 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.

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

**3.5 equalizing voltage:** The voltage, higher than float, applied to a battery to correct inequalities among battery cells (voltage or specific gravity).

**3.6 float voltage:** The voltage applied to a battery to maintain it in a fully charged condition during normal operation.

**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.”

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

**3.9 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.

**3.10 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.

**3.11 service test:** A test in the as “found condition” of the battery’s capability to satisfy the battery duty cycle.

**3.12 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.

## 4. Safety

### WARNING

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

### 4.1 Protective equipment

The following protective equipment shall be available to personnel who perform battery maintenance work:

- 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.
- f) Class C fire extinguisher

NOTE—Some battery manufacturers do not recommend the use of CO<sub>2</sub> Class C fire extinguishers due to the potential of thermal shock.

- g) Adequately insulated tools

NOTE—Barriers to prevent the spread of acid spills are extremely important when moving cells such as during battery installation or removal activities.

## 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) Ensure that the load test leads are clean, in good condition, and connected with sufficient length of cable to prevent accidental arcing in the vicinity of the battery.
- d) Ensure that all connections to load test equipment include appropriate short-circuit protection.
- e) Ensure that battery area ventilation is operating per its design.
- f) Ensure 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, ensure 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 aid in ensuring that it is capable of satisfying 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.

(See IEEE Std 484-1996 for initial installation requirements.)

## 5.2 Inspections

Implementation of periodic inspection procedures 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 battery terminals
- b) General appearance and cleanliness of the battery, the battery rack and/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
- 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) Specific gravity of 10% of the cells of the battery if battery float charging current is not used to monitor state of charge
- c) Electrolyte temperature of 10% or more of the battery cells

### 5.2.3 Yearly

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

- a) Specific gravity and temperature of each cell.
- b) 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.]
- c) Cell-to-cell and terminal connection resistance. (See Annex F.)
- d) Structural integrity of the battery rack and/or cabinet.

## 5.2.4 Special inspections

If the battery has experienced an abnormal condition (such as a severe discharge or overcharge), an inspection should be made to ensure that the battery has not been damaged. Include the requirements of 5.2.1, 5.2.2, and 5.2.3.

## 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 corrosion is noted, remove the visible corrosion and check the resistance of the connection.
- c) If resistance measurements obtained in 5.2.3, item c) 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 484-1996 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 subclause 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  $\pm 0.05$  V for lead-calcium cells and  $\pm 0.03$  V for lead-antimony cells.
- b) 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 Clause 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 assurance that the available battery capacity will be maximized. 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) Assurance that the ampere hours returned to the battery are greater than the ampere hours removed plus the charging losses.

### 5.4.2 Charging current indicator

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

### 5.4.3 Specific gravity indicator

Specific gravity (S.G.) 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

- Recharge,
- Equalizing charge, or
- Water addition

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.

## 6. Test schedule

The schedule of tests listed in 6.1 through 6.4 is used to

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

### 6.1 Acceptance

An acceptance test of the battery capacity (see 7.4) should be made, as determined by the user, either at the factory or upon initial installation. The test should meet a specific discharge rate and be for a duration relating to the manufacturers rating or to the purchase specifications requirements.

Batteries may have less than rated capacity when delivered. Unless 100% capacity upon delivery is specified, initial capacity can be as low as 90% of rated. Under normal operating conditions, capacity should rise to at least rated capacity in normal service after several years of float operation. (See IEEE Std 485-1997.)

Acceptance tests of 1 hour or less should use the rate-adjusted method of 7.3.2. If the aim of the test is to verify performance against manufacturers published data, the rate should not be adjusted for the end of life condition, i.e., perform the test at the full published rate adjusted for temperature. If the aim is to establish a baseline for future performance testing, adjust the rate for the end of life condition.

### 6.2 Performance

- a) A performance test of the battery capacity (see 7.4) should be made within the first two years of service. It is desirable for comparison purposes that the performance tests be similar in duration to the battery duty cycle.
- b) Batteries should undergo additional performance tests periodically. When establishing the interval between tests, factors such as design life and operating temperature (see Annex H) should be considered. It is recommended that the performance test interval should not be greater than 25% of the expected service life.
- c) Annual performance tests of battery capacity should be made on any battery that shows signs of degradation or has reached 85% of the service life expected for the application. Degradation is indicated when the battery capacity drops more than 10% from its capacity on the previous performance test, or is below 90% of the manufacturers rating. If the battery has reached 85% of service life, delivers a capacity of 100% or greater of the manufacturer's rated capacity, and has shown no signs of degradation, performance testing at two-year intervals is acceptable until the battery shows signs of degradation. If capacity is calculated by the rate-adjusted method (see 7.3.2.2), degradation can be indicated by a capacity drop of less than 10% from the previous test, depending on the discharge rate. Contact the manufacturer for further guidance.
- d) If performance testing is to be used to reflect baseline capacity or benchmark (the most accurate form of battery trending) capacity of the battery, then perform requirements a) through f) of 7.1. If performance testing is to be used to reflect maintenance practices as well as trending, then omit