



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

IEEE Power and Energy Society

Developed by the
Stationary Battery Committee

IEEE Std 450™-2020
(Revision of IEEE Std 450-2010)



STANDARDS

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

Developed by the

Stationary Battery Committee
of the
IEEE Power and Energy Society

Approved 3 December 2020

IEEE SA Standards Board

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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. Guidance to determine when batteries should be replaced is also provided. 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 450-2020, 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 semiportable 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™ and IEEE Std 485™, will provide the user with a general guide to sizing, designing, placing in service, maintaining, and testing a vented lead-acid storage battery installation.¹ IEEE Std 535™ [B5] provides a standard for qualification of Class 1E lead storage batteries for nuclear power generating stations.²

¹Information on references can be found in [Clause 2](#).

²The numbers in brackets correspond to those of the bibliography in [Annex M](#).

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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 service. It also provides guidance to determine when batteries should be replaced. This recommended practice is applicable to standby service stationary applications where a battery charger normally maintains the battery fully charged and provides the dc loads.

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 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (shall equals is required to).^{3,4}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (should equals is recommended that).

The word *may* is used to indicate a course of action permissible within the limits of the standard (may equals is permitted to).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (can equals is able to).

1.4 Exclusions

Specific applications, such as emergency lighting units, photovoltaic, cycling, and semiportable 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.

³The use of the word *must* is deprecated and shall not be used when stating mandatory requirements, *must* is used only to describe unavoidable situations.

⁴The use of *will* is deprecated and shall not be used when stating mandatory requirements, *will* is only used in statements of fact.

1.5 Document organization

This recommended practice is divided into [12](#) ~~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 standards⁷ 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 [13](#) ~~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

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 484™, IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications (ANSI/BCI).^{5,6 12}

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

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

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

IEEE Std 1635™, IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications.⁷

IEEE Std 1657™, IEEE Recommended Practice for Personnel Qualifications for Installation and Maintenance of Stationary Batteries.

3. Definitions, acronyms⁷ and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be referenced for terms not defined in this clause.⁸ ~~Glossary of Terms & Definitions should be consulted for terms not defined in this clause.~~³

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^{6 1} IEEE publications are available from The Institute of Electrical and Electronics Engineers (<https://445-Hoes-Lane,P.O.Box-1331,Piscataway,NJ-08855-1331,USA>) (<http://standards.ieee.org/>).

⁷ASHRAE publications are available from the American Society of Heating, Refrigerating and Air Conditioning Engineers (<https://www.ashrae.org/>).

⁸ ~~The~~ IEEE Standards Dictionary Online ~~Glossary of Terms & Definitions~~ is available at: <http://dictionary.shop.ieee.org>. An IEEE account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.~~+~~

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

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

critical period: The period of maximum current during ~~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.

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

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

float charge: A constant voltage ~~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 through a battery during a float charge.

float voltage: The voltage applied to a battery during ~~a float~~ operation ~~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.

performance test: A constant-current or constant-power capacity test made on a battery after being ~~it has been~~ in service.

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: [External](#) connections made between cells/[units](#), or at the positive and negative terminals of the battery, which may include terminal plates, cables with lugs, and connectors.

vented cell: A [lead acid](#) 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 [Acronyms and abbreviations](#)

~~S.G.~~ ~~specific gravity~~

[ICV](#) [individual cell voltage](#)

MPT modified performance test

[OCV](#) [open circuit voltage](#)

[S.G.](#) [specific gravity](#)

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 [educated, trained and qualified to work on](#) ~~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 [and used as appropriate for the specific task](#):

- 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 ~~g grams~~ bicarbonate of soda to 1 ~~L liter~~ of water, to neutralize minor acid spillage

f) Absorption material, neutralization material, or a combination of the two

NOTE 1—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.⁹

- g) Class C fire extinguisher

NOTE 2—Some battery manufacturers do not recommend the use of CO₂ Class C fire extinguishers due to the potential of thermal shock.

- h) Adequately insulated tools
- i) Methods ~~Barriers~~ to control ~~prevent~~ the spread of acid spills must be available ~~are extremely important~~ when moving cells such as during battery installation or removal activities. See IEEE Std 1578⁴ for information on spill control ~~barriers~~.
- j) Arc-flash personal protective equipment as required by the job hazard analysis (see IEEE Std 1657).

⁹Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

⁴~~Information on references can be found in Clause 2.~~

4.2 Precautions

A job hazard analysis should be performed prior to performing any work or maintenance on a battery. The following protective procedures shall be observed during maintenance:

- a) Use caution when working on batteries since they may represent a shock and/or arc flash 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. See IEEE Std 1635.
- 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 avoid ~~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. [Only](#) personnel knowledgeable of batteries and the safety precautions involved shall perform battery maintenance.

(See IEEE Std 484 for initial installation requirements [and IEEE Std 1657 for technician qualifications.](#))

5.2 Inspections

[5.2.1 General](#)

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 [be complete immediately](#)~~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.

5.2.2 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 in battery area ~~and~~
- h) Ensure ventilation system HVAC is functional
- i) Pilot cells (if used) voltage and electrolyte temperature
- j) 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 and A.4.)
- k) Unintentional battery grounds
- l) Operational status of all battery monitoring systems, including connections, are in working order ~~operational~~ (if installed)

5.2.3 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) Temperature of a representative sample of 10% of the battery cells (Example for a 60 ~~sixty~~ cell string, measure the temperature of every tenth cell for a total of 6 ~~six~~ cells.) These same cells should be used for readings in item c) and item d).
- c) For lead-antimony batteries, specific gravity of 10% of the cells of the battery (see 5.4.32) and float charging current.

- d) For technologies other than lead-antimony, if battery float charging current is not used to monitor state of charge, specific gravity of 10% of the cells of the battery (see 5.4.[32](#)).

5.2.4 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 of all cells of the battery (see 5.4.[32](#)).
- 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.[32](#)).
- 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.[21](#). 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).

5.2.5 Special inspections

A complete set of specific-gravity readings should be recorded upon initial installation [after the battery has been determined to be at full state of charge](#) and after two years of service on all cell types.

If the battery has experienced an abnormal condition, an inspection should be made to verify that the battery has not been damaged. Include the requirements of 5.2.[21](#), 5.2.[32](#), and 5.2.[43](#). Contact the battery manufacturer for assistance.

With center tapped batteries that do not have a separate charging system that is installed to support the tapped section of batteries, a special inspection should be performed to determine the impact on the tapped cells of the abnormal event to be considered as a load on those cells. The tapped portion of the battery cells need to be inspected to verify that they are not in a partially discharged condition. This can be detected as mild sulfation if caught early, and observed as differing values of ICVs.

5.2.6 Monitoring

Battery monitoring can be used to enhance data collection, trending (see Clause 10)⁷ 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 5.2.⁴³ or conducting discharge tests at the frequency defined in Clause 6. See IEEE Std 1491. ~~"IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications."~~

5.3 Corrective actions

5.3.1 General

The corrective actions listed in 5.3.²¹ through 5.3.⁴³ are meant to provide optimum life of the battery. However, the corrective actions in and of 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.

5.3.2 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 action⁷.

- 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 5.2.43, item d) or 5.3.24, 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, re-torque and retest. If baseline values are unavailable, contact the manufacturer for acceptable values. If there are no baseline values and no recommendations from the manufacturer, re-torque and retest any connection that is > 10% above the average value. 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 multitier 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 g grams of soda to 1 L liter of water. Avoid the use of hydrocarbon-type cleaning agents (oil distillates) and strong alkaline cleaning agents, which may cause crazing or cracking in 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.

5.3.3 Equalizing charge

Item a) though item ~~c 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 ~~h~~ ~~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, then an equalizing charge is desirable (see C.3.1).
- b) If an undercharge condition is suspected (low individual cell voltage, plate sulfation, etc.), specific-gravity readings should be taken on the suspect cells (see Annex B), ~~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, then an equalizing charge should be given (see C.1).

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](#)).

5.3.4 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

5.4.1 General

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, but it drops ~~and~~ exponentially as the battery voltage approaches ~~related to time when~~ the charger set-point ~~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.14).

5.4.2 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 compensated for battery ~~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.

5.4.3 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

5.5 ~~4.3 Charging (Float) current~~ indications and interpretations ~~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). These measurements can also be used to indicate the operation of the charger and ~~for~~ the continuity of the entire system, but not the integrity_z of the cell connections.

Trending of float current measurements can provide users with useful information related to the state of health of the battery.

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_z 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 designs, an increase in float current over life is normal, but, an increase of four times the initial charging current and a doubling of the initial charging current in low-antimony (commonly referred to as Selenium) 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 perform the following:

- a) Determine whether the battery meets its specification~~7~~ or the manufacturer's rating, or both~~7~~.
- b) Periodically determine whether the performance of the battery is within acceptable limits~~7~~.
- c) ~~If required~~, Determine whether the battery~~7~~ as found~~7~~ meets the design requirements of the system to which it is connected~~7~~.

6.2 Acceptance

An acceptance test of the battery capacity (see 7.5) should be made at the manufacturer's factory or upon initial installation, as determined by the user. The test should meet a specific discharge rate and duration relating to the manufacturer's rating or to the purchase specification's requirements.

All inspections listed in 5.2 should also be completed before performing an on-site acceptance test.

The initial capacity of every cell should be at least 90% of rated capacity. Note that battery strings may have less than rated capacity when delivered unless a battery capacity of 100% upon delivery is specified, but in no case should any cell be less than 90%. This may rise to rated capacity after several charge—discharge cycles or after a period of float operation ~~(IEEE Std 485)~~. The acceptance criteria should be based on ~~a time-adjusted calculation (see 7.4.2.2)~~ running the full published rate. For UPS applications, refer to IEEE Std 1184™ [B7].

An acceptance test could establish the baseline capacity for trending purposes. ~~If the time-adjusted method (see 7.4.2) will be used for future performance tests, then the above time-adjusted calculation can be used for the baseline. If the rate-adjusted method (see 7.4.3) will be used for future testing, then an additional capacity calculation should be performed in accordance with 7.4.3.5 to establish the baseline.~~

6.3 Performance

Performance is evaluated as follows:

- a) A performance test of the battery capacity (see 7.5) 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) If changing from the time-adjusted to the rate-adjusted method, then an additional capacity calculation is required in accordance with 7.4.3.5 to establish the new baseline.
- c) 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.

Annual performance tests of battery capacity should be conducted ~~made~~ on any battery that shows signs of degradation or has reached 85% of the service life expected for the application. For purposes of this determination, degradation is indicated when the battery capacity drops by more than 10% from its capacity on the previous performance test or is below 90% of the manufacturer's rating. If the battery has reached 85% of service life expected for the application, 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 7.4.4.1~~3.5~~), 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 [requirement ~~requirements~~ a\)](#) through [requirement f\)](#) of 7.2. If performance testing is to be used to reflect maintenance practices as well as trending, then omit requirement a), perform requirement b), but take no corrective action unless there is a possibility of permanent damage to the battery, and perform [requirement ~~requirements~~ c\)](#) through [requirement f\)](#) of 7.2. If on a performance test that is used to reflect maintenance practices, the battery does not deliver its expected capacity, then the test should be repeated after [requirement ~~the requirements of 7.2~~ a\)](#) and [requirement b\)](#) of 7.2 have been completed.

6.4 Service

A service test of the battery capability (see 7.6) may be required by the user to meet a specific application requirement. This is a test of the battery's ability, as found, to satisfy the battery duty cycle. A service test should be scheduled at the discretion of the user at periodic times between performance tests. When a service test is also being used on a regular basis, it will reflect maintenance practices. When a battery has shown signs of degradation, service testing should be performed on its normal frequency, and performance testing should be performed on an annual basis.

6.5 Modified performance test

A modified performance test (see 7.5) is a test of battery capacity using a constant current, modified by increasing the current to bound the currents in the duty cycle. The locations and duration of the changes in current levels could have profound effects on the battery's ability to maintain its minimum required voltage.

Initial conditions for the modified performance test should be identical to those specified for a service test. The system designer and the battery manufacturer should review the design load requirements to determine if the modified performance test is applicable and to determine the test procedure. See Annex I for typical modified performance test types and examples.

A modified performance test can be used in lieu of a service test and/or a performance test at any time. If the battery has been sized in accordance with IEEE Std 485, then the battery is acceptable if it delivers a tested capacity of 80% or greater. Bypassing of cells [~~(see [requirement g](#) of 7.5]~~^{5g}) is not allowed during the duty cycle portion (service test) of a modified performance test. Bypassing of cells is allowed after the duty cycle duration (service test) of the test is satisfied.

7. Procedure for battery tests

7.1 General

These procedures describe the recommended practices for discharge testing a battery. ~~All testing should follow the precautions listed in 4.2.~~

If the tools are available, thermographic monitoring of battery cells, connections, disconnect switches, load banks, [and so on](#) ~~etc.~~ during a battery discharge test should be performed. Thermography is a diagnostic tool to find temperature deviations before equipment failure.

7.1.1 Parallel string testing

7.1.1.1 Parallel string performance [and service](#) testing

In some cases, it is not possible to break parallel strings apart for performance testing purposes. While not recommended, performance testing of parallel battery strings is possible and may provide valuable data to both the user and the manufacturer. [For some applications, it may be necessary to test the parallel strings at one time, for example, when batteries are connected to a UPS system \(see IEEE Std 1184 \[B7\]\). Service tests of parallel string batteries require that the strings be tested simultaneously](#) ~~However, the value of the results depends on the actual load profile on each individual string.~~

The test equipment used during the performance test shall, at a minimum, be capable of monitoring the overall battery or dc bus voltage, individual string voltages, test duration, and individual string currents. ~~The test equipment should be capable of monitoring individual cell voltages. During the performance of the load test, periodic measurements should be recorded for data analysis.~~

When possible, the load test equipment should be connected to the dc system bus. When connecting to the dc bus, the test end voltage should be adjusted to account for the voltage drop between the battery and the dc bus. When the test is started, the voltage drop between the individual battery strings and dc bus should be checked against the design voltage drop. The voltage drop between the individual strings and the dc bus should be recorded. If any voltage drop is significantly greater than the design voltage drop, the test should be stopped and the battery returned to charge until the cause can be determined and corrected.

Significant deviations from a constant discharge rate in any string may compromise the data analysis and subsequent battery calculation. The magnitude and duration of the current deviations will need to be analyzed to determine the effect on the results.

7.1.1.2 Service testing of parallel string batteries

~~Service tests of parallel string batteries require that the strings be tested simultaneously. The test equipment used during the performance of the service test should, at a minimum, be capable of monitoring the overall battery bus voltage, individual string voltages, individual cell voltages, individual string currents, and duration of the test. When possible, the load test equipment should be connected to the dc system bus. When connecting to the dc bus, the minimum voltage may need to be adjusted for the design voltage drop between the battery terminals and the dc bus. During test performance, periodic measurements should be recorded for data analysis and to monitor individual string discharge rate.~~

7.1.2 Testing of substrings

Under certain circumstances, a large string of cells (e.g., 120+ cells) may need to be broken down into two or more substrings to accommodate testing. This may be due to an equipment limitation, safety concerns, and/or heating concerns. Substrings should be tested in the same manner as strings. To determine the capacity, the voltage profile of each subsection test should be combined. The end voltage and end time should be determined from the composite voltage profile. If the substrings are not discharged equally, within 5%, an off-line charger may be required ~~in order~~ to fully charge each substring.

CAUTION 1

The user should be cautioned that if each substring is not discharged for the same amount of time, there may be problems recharging the string using the system charger. For this reason, the time of test for each substring should be nearly identical to remove that same amount of ampere-hours to facilitate recharge of the entire battery string. This may cause some substrings to be tested past the desired end voltage or before the specified end voltage is reached.

CAUTION 2

There may be a risk of cell damage if a substring is tested significantly past the specified end voltage. If the test is terminated prior to the substring voltage reaching the specified end voltage, a determination of capacity to that end voltage will not be possible.

7.2 Initial conditions

The following list gives the initial requirements for all battery capacity tests except as otherwise noted:

- a) Equalize the battery if recommended by the manufacturer and then return it to float for a minimum of 72 h ~~hours~~.
- b) Check all battery connections and verify that all resistance measurements are correct for the system [~~(see item d) of 5.2.4]~~ 3d).
- c) Record the float current of the string and float voltage of each cell just prior to the test. For lead- antimony cells, the specific gravity of each cell should also be recorded prior to the test.
- d) Record the electrolyte temperature of 10% or more of the cells to establish an average temperature. When test duration is expected to exceed 24 h, record electrolyte temperature every 8 h throughout the discharge ~~(suggested every sixth cell)~~.