IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications

Sponsor

IEEE Standards Coordinating Committee 29
on Stationary Batteries

Approved 20 June 1996

IEEE Standards Board

Abstract: Maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of valve-regulated lead-acid (VRLA) batteries for stationary applications are covered. Guidance to determine when batteries should be replaced is also provided.
Keywords: acceptance test, battery capacity, battery maintenance, battery testing, corrective action, float voltage, inspection, internal ohmic measurements, maintenance, performance test, precautions, protective equipment, recombinant, ripple current, state-of-charge, stationary batteries, test procedures, test schedules, thermal runaway, valve-regulated lead-acid (VRLA) batteries

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The Institute of Electrical and Electronics Engineers, Inc.
345 East 47th Street, New York, NY 10017-2394, USA

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ISBN 1-55937-747-X

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Introduction

[This introduction is not a part of IEEE Std 1188-1996, IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.]

Stationary lead-acid batteries play an ever increasing role in industry today by providing backup power for a wide range of applications. IEEE Std 450-1995 has provided the users with standard practices for battery maintenance, testing, and replacement for vented batteries. With the introduction of the valve-regulated lead-acid (VRLA) battery several years ago, there are unique characteristics that are not covered by the existing documents. This recommended practice fulfils the need within industry to provide common or standard practices for battery maintenance, testing, and replacement of VRLA batteries for stationary applications.

This recommended practice may be used separately, and when combined with IEEE Std 1187-1996, IEEE Std 1189-1996, and IEEE Std 485-1983, will provide the user with a general guide to selection, sizing, designing, installing, and testing a VRLA battery installation.

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IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications

1. Scope

This recommended practice is limited to maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of valve-regulated lead-acid (VRLA) batteries for stationary applications. It also provides guidance to determine when batteries should be replaced. There are other maintenance/test procedures and replacement techniques used within the industry (especially for smaller VRLA batteries) that are equally as effective but are beyond the scope of this recommended practice. The user must consider their particular application and recent developments in the state-of-the-art when using this recommended practice. Users are cautioned to be aware of the wide variance of practices that exist in the industry for this new technology.

The portions of this recommended practice that specifically relate to personnel safety are mandatory instructions and are designated by the word *shall;* all other portions are recommended practices and are designated by the word *should*.

This recommended practice does not include any other component of the dc system, nor surveillance and testing of the dc system, even though the battery is part of that system.

Sizing, installation, qualification, selection criteria, other battery types, and application are also beyond the scope of this recommended practice.

2. References

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

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).[1]

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[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.

IEEE Std 485-1983, IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations.

IEEE Std 1187-1996, IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications.

IEEE Std 1189-1996, IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications.[2]

3. Definitions

The following definitions apply specifically to the subject matter of this recommended practice. For other definitions, refer to IEEE Std 100-1992 and other documents referenced in clause 2.

3.1 acceptance test (battery): Capacity test made on a new battery to determine that it meets specifications or manufacturer's ratings.

3.2 battery cabinet: A structure used to support and enclose a group of cells.

3.3 battery rack: A structure used to support a group of cells.

3.4 capacity test (battery): A discharge of a battery at a constant current or a constant power to a specified voltage.

3.5 continuity test (battery): A test on a cell/unit or battery to determine the integrity of its conduction path.

3.6 internal ohmic measurements (battery): The measurement of either the internal impedance, conductance, or resistance of battery cells/units.

3.7 module: Multiple cells/units in a single assembly.

3.8 performance test (battery): A constant current or a constant power capacity test made on a battery after being in-service, to detect any changes in capacity.

3.9 recombinant: *Syn:* oxygen recombination. Refer to IEEE Std 1189-1996.

3.10 service test (battery): A special test of the battery's capability, as found, to satisfy the design requirements (battery duty cycle) of the dc system.

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

3.12 unit: Multiple cells in a single jar.

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

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[2] As this standard goes to press, IEEE Std 1189-1996 is approved but not yet published. The draft standard is, however, available from the IEEE. Anticipated publication date is September 1996. Contact the IEEE Standards Department at 1 (908) 562-3800 for status information.

4. Safety

CAUTION

As with other batteries, VRLA 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) Class C fire extinguisher
f) Bicarbonate of soda, mixed 0.1 kg to 1 L (1 lb to 1 gal) of water, to neutralize acid spillage
g) Adequately insulated tools

NOTE—Some battery manufacturers do not recommend the use of CO_2 Class C fire extinguishers due to the potential of thermal shock.

4.2 Precautions

The following protective procedures shall be observed during maintenance:

a) Use caution when working on batteries since they present a shock hazard.

b) Prohibit smoking and open flames, and avoid 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 short-circuit protection.

e) Ensure that battery area and/or cabinet ventilation is operable.

f) Ensure unobstructed egress from the battery area.

g) Avoid wearing metallic objects such as jewelry.

h) Neutralize static buildup just before working on the battery by having personnel contact the nearest effectively grounded surface.

i) Ensure that all monitoring systems are operable.

j) Do not remove vents.

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 determining the need for battery replacement. The users must consider their particular application and reliability needs if maintenance procedures other than those recommended in this recommended practice are used. Battery maintenance should be performed by personnel knowledgeable of batteries and the safety precautions involved.

5.2 Inspection

All inspections should be made under normal float conditions if possible. Readings should be taken in accordance with the manufacturer's instructions. Refer to the annexes for more information. All measurements and observations should be recorded for future comparisons.

5.2.1 Monthly

A monthly general inspection should include a check and record of

a) Overall float voltage measured at the battery terminals
b) Charger output current and voltage
c) Ambient temperature and the condition of ventilation and monitoring equipment
d) Visual individual cell/unit condition check to include
    1) Cell/unit integrity for evidence of corrosion at terminals, connections, racks, or cabinet
    2) General appearance and cleanliness of the battery, the battery rack or cabinet and battery area, including accessibility
    3) Cover integrity and check for cracks in cell/unit or leakage of electrolyte
    4) Excessive jar/cover distortion

5.2.2 Quarterly

A quarterly inspection should include the items in 5.2.1 and a check and record of the following (values recorded and observations made should be compared to initial inspection values):

a) Cell/unit internal ohmic values (see D.4).
b) Temperature of the negative terminal of each cell/unit of battery (see B.3).
c) For applications with a discharge rate of 1 h or less, a representative sample of the intercell connection detail resistances (minimum 10% or six connections). If an upward trend is detected from the initial readings, measure all connection resistances, determine the cause, and take corrective action as needed. Test different connections each quarter. (See D.1.)

5.2.3 Semiannual

A semiannual inspection should include the items of 5.2.1 and 5.2.2, as well as a check and record of the voltage of each cell/unit.

5.2.4 Yearly and initial

The yearly inspection and the initial installation should include the items in 5.2.1, 5.2.2, and 5.2.3, and a check and record of the following:

a) Cell-to-cell and terminal connection detail resistance of entire battery (see D.1)
b) AC ripple current and/or voltage imposed on the battery (see D.5 and consult the manufacturer)

5.2.5 Special inspections

If the battery has experienced an abnormal condition (such as a severe discharge, overcharge, or extreme high ambient temperature), an inspection should be made to ensure that the battery has not been damaged. Include the requirements for the yearly inspection.

5.3 Corrective actions

5.3.1 Immediate

The following items indicate conditions that should be corrected prior to the next general inspection:

a) If resistance readings obtained in 5.2.2 item c) are more than 20% above the installation value or above a ceiling value established by the manufacturer, or if loose connections are noted, retorque and retest. If terminal corrosion is noted, clean the corrosion and check the resistance of the connection. If the retested resistance value remains unacceptable, the connection should be disassembled, cleaned, reassembled, and retested. See D.1.

b) When cell/unit internal ohmic values deviate by a significant amount from either the installation value, or from the average of all the connected cells/units, additional actions are needed. (See D.4 for guidance.)

c) If any electrolyte is found, determine the source and institute repair or replacement. When excessive dirt is noted on cells or connectors, wipe with water-moistened clean wiper. Remove any electrolyte seepage on cell covers and containers with a bicarbonate of soda solution 0.1 kg to 1 L (1 lb to 1 gal) of water. Do not use hydrocarbon-type cleaning agents (oil distillates) or strong alkaline cleaning agents, which could cause containers and covers to crack or craze. Use extreme care when cleaning battery systems to prevent ground faults (see clause 4).

d) When the float voltage, measured at the battery terminals, is outside of its recommended operating range, the charger voltage should be adjusted. The float voltage may require temperature compensation (see annex B).

5.3.2 Routine

The following items 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 may be accomplished prior to the next quarterly inspection, provided that the battery condition is monitored at regular intervals.

a) If any cell/unit voltage is below its respective critical minimum voltage as specified by the manufacturer, corrective action, which includes an equalizing charge, should be given (see D.3). Do not charge at rates above the manufacturer's recommendation for the specific ambient temperature involved.

b) When cell temperatures deviate more than 3 °C (5 °F) from each other during a single inspection, determine the cause and correct. If sufficient correction cannot be made, contact the manufacturer for allowances that must be taken.

c) See the annexes for a more detailed discussion of these abnormalities and the urgency of corrective actions.

6. Test description and schedule

The following schedule of tests can be 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, as found, 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.

Recording test data (battery voltage and individual cell voltage during the capacity test and the capacity to end-of-discharge voltage) for trending purposes provides the user with a means of predicting future performance and anticipated battery replacement time.

6.1 Acceptance

An acceptance test of the battery capacity (see 7.4) 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.

Batteries may have less than rated capacity when delivered. Unless 100% capacity upon delivery is specified, initial capacity can be in the range of 90–95% of rated capacity. This will rise to rated capacity after several charge-discharge cycles or after a period of float operation (see IEEE Std 485-1983).

6.2 Continuity test

A continuity test will determine the physical integrity of the battery system, but not necessarily the performance of the battery (see 7.6). This test is done with the semiannual maintenance described in 5.2.3, in accordance with the manufacturer's recommendations, or when internal ohmic measurements cannot be performed.

6.3 Performance

A performance test of the battery capacity should be given at one year intervals until it shows signs of degradation, at which time semiannual performance tests should be given. 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 manufacturer's published ratings. It is desirable, for comparison purposes, that the performance test be similar in duration and discharge rate to the battery acceptance test.

Follow the initial conditions as described in 7.1, if performance testing is to be used to reflect baseline capacity or benchmark (trending) of the capacity of the battery. When it is desirable to reflect all factors, including maintenance, that determine the battery capability, the initial test conditions should be as described in 7.1, omitting requirements a) and b). If the battery does not deliver its expected capacity, when the test includes maintenance practices, the test should be repeated after the requirements of 7.1 a) and b) have been completed.

NOTE—When the battery is required to supply varying loads for specified time periods (a load duty cycle), the performance test may not substantiate the battery's capability to meet all design loads, particularly if high-rate, short-duration loads determine the battery size.

6.4 Service

This is a test of the battery's ability, usually as found, to satisfy the design requirements (battery duty cycle) of the dc system. When a service test is conducted on a regular basis, it will reflect maintenance practices when 7.1 requirements a) and b) are omitted. Trending battery voltage during the critical periods of the load duty cycle will provide the user with a means of predicting when the battery will no longer meet design requirements. If the system design changes, sizing (see IEEE Std 485-1983) will have to be reviewed, and the service test will have to be modified accordingly.

7. Procedure for battery tests

This procedure describes the recommended practice for testing the battery. All testing should follow the safety requirements listed in clause 4.

7.1 Pretest requirements

The following defines the activities and data required prior to initiating a discharge test, except as noted in clause 6.

a) If an equalizing charge is specifically recommended by the manufacturer, verify that it has been completed more than three days and less than thirty days prior to the start of the test.

b) Check all battery connections and ensure that all resistance readings are correct for the system (see 5.3.1).

c) Read and record the float voltage of each cell/unit just prior to the test.

d) Read and record the temperature of the battery cell/unit to determine an average battery temperature (suggest 10% or more cells/units).

e) Read and record the battery terminal float voltage.

f) Measure and record individual cell/unit internal ohmic values prior to the test.

g) Take adequate precautions (such as isolating the battery to be tested from other batteries and critical loads) to ensure that a failure will not jeopardize other systems or equipment.

7.2 Test length

The recommended procedure is to perform a capacity test for approximately the same length of time as that for which the battery was sized (see note in 6.3).

7.3 Test discharge rate

The discharge rate depends on the type of test selected. For the acceptance test or performance test, the discharge rate should be a constant current or constant power load equal to the manufacturer's rating of the battery for the selected test length and final voltage. See 7.5 for the test discharge rate of the service test.

NOTE—The test discharge rate or capacity should be corrected for temperature. See annex C (or contact the manufacturer) for correction factors applicable to the battery design.

7.4 Acceptance and performance tests

Set up the necessary instrumentation with the provision that the load be varied to maintain a constant current or a constant power discharge equal to the rating of the battery for the selected time.

a) Disconnect the charging source. Connect the load to the battery, start the timing, and continue to maintain the selected discharge rate.

b) Read and record individual cell/unit voltages and the battery terminal voltage. The readings should be taken while the load is applied at the beginning, at specified intervals, and at the completion of the test. There should be a minimum of five sets of readings, if possible.

c) Maintain the discharge rate until the battery terminal voltage decreases to a value equal to the specified minimum voltage per cell times the number of cells (e.g., 1.75 V times the number of cells).

   NOTE—Individual cell voltage readings should be taken between respective terminals of like polarity of adjacent cells/units so as to include the voltage drop of the intercell connectors. Due to the wide diversity of VRLA battery terminal connection designs, the selection of the appropriate voltage probe location must be carefully analyzed to ensure that only the appropriate voltage drops are included. See figure D.1.

d) If an individual cell/unit is approaching reversal of its polarity (0 V) or a module voltage is lower by 2 V or more (compared to the average module voltage), but the terminal voltage has not reached its test limit, the test should be continued with the cell/unit bypassed where feasible. Complete the bypass away from the cell/unit to avoid arcing. The new minimum voltage should be determined based on the remaining cells.

   It is very important that the user work with the manufacturer or other experienced personnel to plan the course of action. The possibility of a weak cell(s) should be anticipated and preparations should be made for bypassing the weak cell(s) with minimum hazard to personnel.

e) Observe the battery for abnormal intercell/unit connector or terminal heating.

f) At the conclusion of the test, determine the battery capacity according to the procedure outlined in 7.9.

7.5 Service test

The system designer should establish the service test procedure and acceptance criteria prior to the test. The recommended procedures for the test are as follows:

a) The initial conditions shall be as identified in 7.1. To reflect maintenance practices by testing in the as found condition, omit 7.1 requirements a) and b).

b) The discharge rate and test length should correspond as closely as is practical to the battery duty cycle.

c) Follow the test procedures outlined in 7.4 items a) through e). The voltage readings should be taken just prior to the end of each load period, and at the completion of the test.

d) If the battery does not meet the battery duty cycle, review its rating to determine if it was properly sized; recharge the battery, and if necessary, inspect the battery as discussed in 5.2.4, take necessary corrective actions, and repeat the service test. A battery performance test (see 6.3) may also be required to determine whether the problem is the battery or the application.

7.6 Continuity test

Perform a short-duration load test on the cell/unit or battery to determine its integrity. Consult with the manufacturer for the test conditions and acceptance criteria.

NOTE—As an example, a continuity test can be performed by opening the ac input for a short period in order to allow the battery to assume the load.

7.7 Restoration

Disconnect all test apparatus. Recharge and return to normal service.

CAUTION

A cell/unit with an internal short shall not be placed on charge (see annex B). The charger must have its output voltage adjusted for the reduced overall system voltage for the remainder of the cells.

7.8 Completion of recharge

The pattern of charging current delivered by a conventional voltage-regulated charger after a discharge provides a method for determining the state of recharge. As the cells approach full charge, the battery voltage rises to approach the charger output voltage setting, and the current decreases. When the charging current has stabilized at the charging voltage, the battery is fully charged. (See annex A for cautions.)

7.9 Determining battery capacity

For an acceptance or performance test, use the following equation to determine the battery capacity:

$$\text{Percent capacity at } 25\ ^\circ\text{C } (77\ ^\circ\text{F}) = (t_a/t_s) \times 100$$

where

t_a is the actual time of the test to specified terminal voltage as corrected for temperatures (see annex C)
t_s is the rated time to specified terminal voltage

For test durations of less than 1 h, consult the manufacturer for applicability.

8. Battery replacement criteria

The recommended practice is to replace the battery if its capacity, as determined in 7.9, is below 80% of the manufacturer’s rating. The timing of the replacement is a function of the sizing criteria utilized and the capacity margin available, as compared to the load requirements. A capacity of 80% shows that the battery rate of deterioration is increasing even if there is ample capacity to meet the load requirements of the dc system. Other factors, such as unsatisfactory service test results (see 7.5), or the addition of new load requirements, may require battery replacement. Physical characteristics, such as abnormally high cell/unit temperatures (see annex B), are often determinants for complete battery or individual cell/unit replacements. Reversal of a cell as described in 7.4 item d) is also a good indicator for further investigation into the need for individual cell/unit replacement. Replacement cells/units, if used, should have electrical characteristics compatible with existing cells/units and should be tested prior to installation. Individual replacement cells or units are not usually recommended as the battery nears its end of life.

A low cell/unit voltage that fails to respond to corrective action is a good indicator for further investigations into the need for replacement (see B.2).

Cells/units that fail during a continuity test should be replaced immediately, if an uncorrectable condition exists.

9. Records

Data, such as indicated in 5.2, should be recorded at the time of installation and as specified during each inspection. Data records should also contain reports on corrective actions (see 5.3) and the results of all tests. Correct interpretation of data obtained from inspection, corrective actions, and tests is important to the operation and life of the batteries.

It is recommended that forms be prepared to record all data in an orderly fashion and in such a way that comparison with past data is convenient. A meaningful comparison will require that all data be converted to a standard base in accordance with the manufacturer's recommendations.

Annex A

(informative)

Determining the state of charge

As the cells approach full charge, the battery voltage rises to approach the charger output voltage, and the charging current decreases. When the charging current has stabilized at the charging voltage, the battery is charged. A stabilized charging current is one that does not change more than ± 10% over a 3 h period when measured in the battery circuit.

Determining charging current is difficult to achieve because

a) The in-line ammeter lacks adequate resolution at the low current levels involved and special monitoring equipment may be required.

b) At 25 °C (77 °F) the stabilized current is typically less than 1 mA per ampere hour of rated capacity.

c) Ripple current from the battery charger and/or load can interfere with the accuracy of the readings.

If the charging voltage has been set at a value higher than normal float voltage without exceeding maximum voltage limits suggested by the battery manufacturer (so as to reduce charging time), it is normal practice to reduce the charging voltage to a float value after the charging current stabilizes. The float current will soon stabilize.

Annex B

(informative)

Voltages

B.1 Battery float voltage

The correct battery float voltage measured at the battery terminals is critical with valve-regulated cells. The battery float voltage must be within the manufacturer's recommended limits and manufacturer's recommendations for considering temperature compensation. (See B.3).

B.2 Individual cell voltages

It is not unusual to observe a wide float voltage range between valve-regulated cells than what is normal for vented-type cells. This is especially true for the first six months after installation. Equalization is not normally used to correct apparent imbalances. (See D.3).

a) *Low-voltage cells*. Low voltage is not, by itself, an indication of the state of charge of a cell. Prolonged operation of cells below the manufacturer's low-voltage limit can reduce the life expectancy of cells.

NOTE—A cell voltage consistently below normal float conditions and not caused by elevated temperature of the cell indicates internal cell problems that may require cell replacement.

b) *High-voltage cells*. A cell voltage that exceeds the cell's high-voltage limit (as specified by the battery manufacturer) has a detrimental effect (e.g., accelerated dryout).

B.3 Effect of temperature on voltage

At a constant battery voltage, the charging current will increase as the temperature of the electrolyte increases. Therefore, cells in a battery at a higher temperature than others indicate a lower cell voltage. An effort should be made to eliminate the cause of any temperature differential between cells.

As a general rule, continuous prolonged use at elevated temperatures will reduce the battery life by approximately one-half for every 8 °C (15 °F) above 25 °C (77 °F) that valve-regulated batteries operate. This effect can be mitigated to some extent by the use of temperature-compensated chargers. Operation at elevated temperatures can also lead to thermal runaway. (See D.2.)

Annex C

(informative)

Temperature correction for capacity testing

Discharge rates published by the manufacturers are normally based on a cell temperature of 25 °C (77 °F). When a capacity test is performed at a different temperature, a correction factor must be applied.

Temperature correction factors may be applied to the test discharge rate, or to the tested capacity (discharge time). It is more common to adjust the discharge rate, and at extreme temperatures this method is likely to give more accurate results.

The effect of temperature on VRLA battery performance varies considerably, depending on factors such as the acid specific gravity and immobilization technique. Therefore, the manufacturers should be contacted for correct factors specific to each VRLA cell design.

a) *Discharge time correction*. If the initial average temperature, T_{init}, as measured at the negative terminal is different from the standard temperature, T_{std} (25 °C or 77 °F), the measured time, t_{act}, is adjusted by means of the following equation to obtain the corrected time, t_{corr}.

$$t_{corr} = t_{act}/[1 + k * (T_{init} - T_{std})]$$

The value of k must be obtained from the manufacturer. Typical values range from 0.004 to 0.011 where T_{std} is 25 °C, or 0.002 to 0.006 where T_{std} is 77 °F.

Note—For a given value of *k*, the above formula will be valid over a relatively narrow range of temperature. Consult the manufacturer for details.

b) *Discharge rate correction*. The discharge rate in amps or watts, specified at 25 °C (77 °F) is divided by the appropriate discharge correction factor for the initial temperature as measured at the negative terminal. Typical discharge rate correction factors are given in table 1.

Table 1—Typical discharge rate correction factors

Electrolyte temperature		Rate correction factor (typical range)
°F	°C	
30	–1.1	1.16–1.43
50	10.0	1.10–1.19
70	21.1	1.01–1.04
77	25.0	1.00
90	32.2	0.94–0.96
110	43.3	0.88–0.92

Annex D

(informative)

Corrective actions

D.1 Connection resistance

It is good practice to read and record intercell and terminal connection detail resistances as a baseline upon installation. It is very important that the procedure be consistent so as to detect upward changes that could be caused by corrosion or loose connections. Increased resistance is a cause for concern and may require corrective action.

Normal installation resistances vary greatly as a function of the size of the installation, e.g., from less than 10 $\mu\Omega$ for a large battery to as much as 100 $\mu\Omega$ or more for a smaller battery. Methods for taking these readings include a meter for reading resistance or conductance or measurement of voltage drop during capacity testing where appropriate. The manufacturer should be contacted for the expected values. It is customary to use either a 20% change in the previously established baseline value or a value exceeding the manufacturer's recommended limit as criteria for initiation of corrective action prior to the next inspection. The timing of corrective actions should be determined by an analysis of the effects of the increased resistance.

D.2 Thermal runaway

When a VRLA cell is operating on float or overcharge in a fully recombinant mode, there is no net chemical reaction and almost all the overcharge energy results in heat generation. If the design of the system and its environment are such that the heat produced can be dissipated and equilibrium can be reached, then there is no thermal runaway problem. However, if the recombination reaction gives rise to a rate of heat evolution that exceeds the rate of heat dissipation, the battery temperature will rise and more current will be required to maintain the float voltage. The additional current results in still more recombination and heat generation, which further raises battery temperature and so on. The net effect can be accelerated dryout and/or melting of the battery. This potential problem is further aggravated by elevated ambient temperatures or by cell or charging system malfunctions. The possibility of thermal runaway can be minimized by the use of appropriate ventilation between and around the cells and by limiting the charger output current and voltage, such as by using temperature compensated chargers. In the gelled electrolyte system, the gel has intimate contact with the plates and the container walls and provides better heat dissipation characteristics than the absorbed electrolyte system, but not as good as the vented ("flooded") system.

D.3 Equalizing charge

Periodic equalizing is not normally required to correct cell/unit imbalance. Equalize charging should not be performed unless specifically recommended by the manufacturer.

D.4 Cell/unit internal ohmic measurements

a) These measurements provide information about circuit continuity and can be used for comparison between cells and for future reference.

b) The internal impedance of a cell consists of a number of factors including: the physical connection resistances, the ionic conductivity of the electrolyte and the activity of the electrochemical processes occurring at the plate surfaces. With multicell units, there are additional contributions due to intercell connections. The resultant lumped impedance element can be quantified using techniques such as the following:

   1) Impedance measurements can be performed by passing a current of known frequency and amplitude through the battery and measuring the resultant ac voltage drop across each cell/unit. The ac voltage measurement is taken between the positive and negative terminals of individual cells or the smallest group of cells possible. Compute the resultant impedance using Ohm's law.

   2) Conductance measurements can be performed by applying a voltage of known frequency and amplitude across a cell/unit and observing the ac current that flows in response to it. The conductance is the ratio of the ac current component that is in-phase with the ac voltage, to the amplitude of the ac voltage producing it.

   3) Resistance measurements can be performed by applying a load across the cell/unit and measuring the step change in voltage and current. The ohmic value is calculated by dividing the change in voltage by the change in current.

c) When measurements are taken, the type of test equipment used, the test points selected, the cell/unit voltages, and the cell/unit temperatures measured at the negative terminal posts should be recorded.

d) Impedance and resistance are inversely related to conductance. If a cell's ohmic value changes, it may be an indication that the cell's capacity is changing.

   Cell/unit ohmic values measured will vary with the specific measurement techniques and the conditions under which the measurements are taken. Impedance and resistance are inversely related to conductance. If a cell's ohmic value changes, it may be an indication that the cell's performance is changing.

   Significant changes in the values typically indicate a significant change in the cell, which may be reflected in its performance. However, limited changes in the specific values obtained do not necessarily indicate that the cell is free of defect or deterioration.

   In the absence of specific guidelines from the instrument manufacturer, changes in ohmic values in excess of 20% should be considered significant. Such changes should be discussed with the battery manufacturer. In the absence of consultation with the battery manufacturer, a performance test should be run to determine the reliability of the battery system.

e) Replacement criteria are application specific. The timing of further action or replacement is dependent on the type of service the battery supplies. A battery that is used in noncritical, light drain applications may be left in service longer than a battery exposed to critical, high-rate or long-duration applications.

D.5 Ripple current

A battery charger with low electrical noise levels must be used for VRLA batteries to limit the ripple current. An acceptable charger is one that does not raise the average fully charged battery operating temperature, as measured at the negative terminal, by more than 3 °C (5 °F) above ambient in a free-standing condition.

D.6 Voltage probe placement

The voltage probe placement is shown in figure D.1.

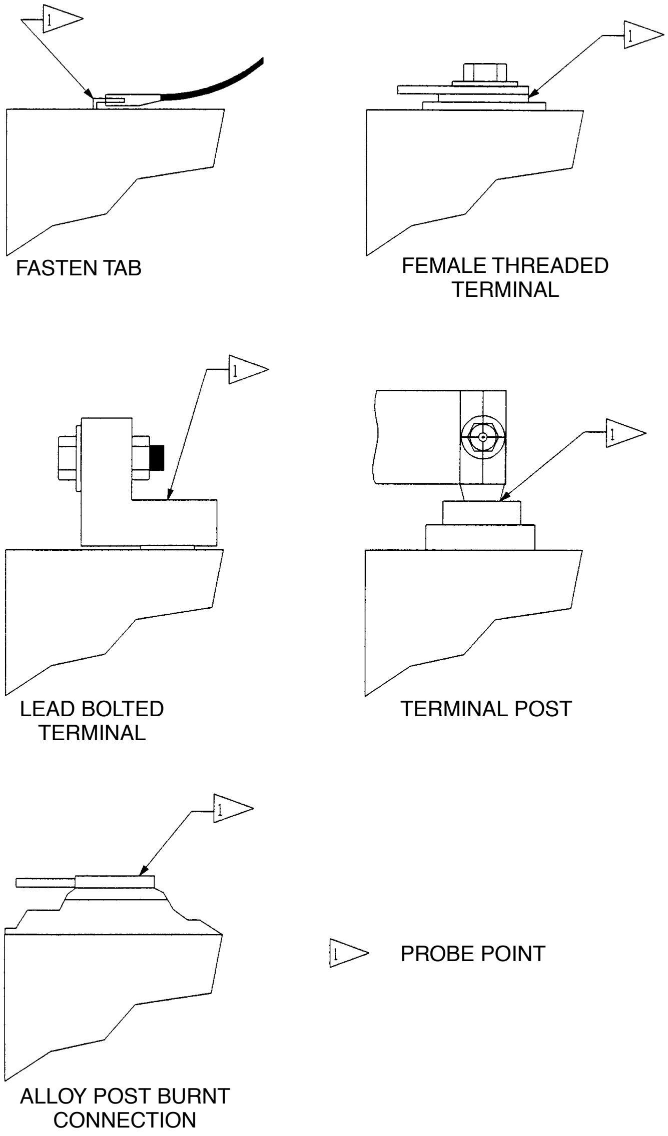

Figure D.1—Voltage probe placement