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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

IEEE

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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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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).[1,2]

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.

[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 and <http://standards.ieee.org/sds/index.html>.

[2]The IEEE standards or products referred to in this clause are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

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_2 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 ±0.05 V for lead-calcium cells and ±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

requirement a), perform requirement b) but take no corrective action unless there is a possibility of permanent damage to the battery, and perform requirements c) through f) of 7.1. 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 the requirements of 7.1 a) and b) have been completed.

6.3 Service

A service test of the battery capability (see 7.5) 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.

6.4 Modified performance test

A modified performance test (see 7.4) is a test of battery capacity using a constant current, modified by increasing the current to bound the currents in the duty cycle. Deviations from the constant-current test, which increase the current, are acceptable. 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 485-1997, then the battery is acceptable if it delivers a tested capacity of 80% or greater. Jumpering out cells is not allowed during the duty cycle portion (service test) of a modified performance test. Jumpering out cells is allowed after the duty cycle duration (service test) of the test is satisfied.

7. Procedure for battery tests

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

7.1 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 hours.

b) Check all battery connections and ensure that all resistance measurements are correct for the system [see 5.2.3 c)].

c) Record the specific gravity and float voltage of each cell or float current of the string and float voltage of each cell just prior to the test.

d) Record the electrolyte temperature of 10% or more of the cells to establish an average temperature (suggested every sixth cell).

e) Record the battery terminal float voltage.

f) 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 and discharge rate

7.2.1 Test length

There are four different types of battery discharge tests presented in this document. They are as follows:

a) Acceptance

b) Performance

c) Modified performance

d) Service tests.

Acceptance, performance and modified performance tests are all tests of a battery's capacity. The service and modified performance tests verify the battery's ability to meet its duty cycle.

— See 7.5 for determining the length of a service test.

— The performance and acceptance tests are presented in 7.4 and the duration is recommended to be approximately the same as the duty cycle. These tests may not confirm the ability of the battery to meet its duty cycle, particularly if very high-rate, short-duration loads determine the battery size.

— The modified performance test is presented in 7.4 and the recommended duration is the duty cycle multiplied by the aging factor used in sizing the battery.

7.2.2 Discharge rate

The discharge rate for a capacity test depends upon the type of capacity test selected. For the acceptance test or performance test, the discharge rate should be a constant-current or constant-power load based on the manufacturer's rating of the battery for the selected test length. See 7.3 for discussion on determining the discharge rate for capacity tests.

In the previous version of this standard, the discharge rate for the time-adjusted method was adjusted for temperature prior to conducting the test. This previous method of temperature compensation is acceptable. In this revision, the time-adjusted method is revised to apply the temperature correction to the capacity calculation after completion of the test. Users may transition to this new method at an appropriate time, e.g., at battery replacement.

The discharge rate for service tests is discussed in 7.5.

Discharge rate determination for modified performance tests is discussed in Annex I.

7.3 Capacity test methods

There are two methods for battery capacity testing: rate-adjusted and time-adjusted. Battery capacities determined by the rate-adjusted method are correct for all test durations. However, this method is more difficult to apply than the time-adjusted method. For tests greater than 1 hour, the time-adjusted method in 7.3.1 is acceptable. The rate-adjusted method in 7.3.2 is used for test durations less than 1 hour. For tests of 1 hour duration, either method can be used. Once a test method is chosen, all subsequent tests should use the same method.

The discharge rate depends upon the type of capacity 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.

7.3.1 Time-adjusted method

When using this method, no correction of any type is required prior to the performance of the test. This method can be used with acceptance tests and modified performance tests and performance tests that have a duration of 1 hour or greater.

7.3.1.1 Temperature factors

In the previous version of this standard, the discharge rate for the time-adjusted method was adjusted for temperature prior to conducting the test. This previous method is acceptable. In this version, the temperature compensation method is revised to apply the temperature correction to the capacity calculation after completion of the test. Users may transition to this new method at an appropriate time, e.g., at battery replacement.

Table 1 shows temperature factors for use in the capacity calculation formula of 7.3.1.2.

Table 1—Recommended time correction factor (K_T) for temperatures other than 25 °C

Initial temperature (°C)	Temperature correction factor K_T	Initial temperature (°C)	Temperature correction factor K_T	Initial temperature (°C)	Temperature correction factor K_T
5	0.684	22	0.966	30	1.045
10	0.790	23	0.977	31	1.054
15	0.873	24	0.986	32	1.063
16	0.888	25	1.000	33	1.072
17	0.902	26	1.006	34	1.081
18	0.916	27	1.015	35	1.090
19	0.929	28	1.025	40	1.134
20	0.942	29	1.036	45	1.177
21	0.954				

NOTE—This table is based on nominal 1.215 specific gravity cells. For cells with other specific gravities, refer to the manufacturer. Manufacturers recommend that battery testing be performed between 18°C and 32°C. These values are average for all time rates between 1 hour and 8 hours. See Annex L for the Fahrenheit conversion for Table 1.

7.3.1.2 Time capacity determination

The following equation is used to determine the battery capacity for an acceptance test, a performance test, or a modified performance test that runs 1 hour or longer for the time adjusted method:

$$\% \text{ capacity at } 25\ °\text{C} = [t_A / (t_S \times K_T)] \times 100$$

where:

t_A = actual time of test to specified terminal voltage [see 7.4 c)],
t_S = rated time to specified terminal voltage,
K_T = correction factor for the electrolyte temperature prior to the start of the test (See Table 1).

7.3.2 Rate-adjusted method

This method is used for performance or acceptance tests of 1 hour or less. See Annex K for a discussion on the time-adjusted and rate-adjusted methods.

In this method, the published rating for the selected test length must be derated to simulate the end-of-life condition. The derating factor is based on the aging factor used in the sizing calculation (see IEEE Std 485-1997), or, if this is not known, on the accepted end-of-life capacity for the battery. In no case will this factor be less than 80% (see Clause 8), nor will the test discharge rate be less than the continuous load current for the application.

The test discharge rate is the manufacturer's published rating multiplied by the derating factor. For an end-of-life capacity of 80%, the test rate will be 80% of the published rate. The test rate is further adjusted for initial battery temperature in accordance with the factors in Table 2.

When testing a relatively new battery using this method, the actual test time may be considerably longer than the nominal time. It is important for trending purposes that the test is always run to the final voltage [see 7.4 item c)]. Battery capacity for the rate-adjusted method is determined in accordance with 7.3.2.2.

7.3.2.1 Rate-adjusted temperature compensation factors

Table 2 shows temperature factors for use in the capacity calculation formula of 7.3.2.2.

Table 2—Recommended rate correction factor (K_C) for temperatures other than 25 °C

Initial temperature (°C)	Temperature correction factor K_C	Initial temperature (°C)	Temperature correction factor K_C	Initial temperature (°C)	Temperature correction factor K_C
5	1.289	22	1.031	30	0.956
10	1.190	23	1.021	31	0.949
15	1.119	24	1.010	32	0.941
16	1.110	25	1.000	33	0.937
17	1.094	26	0.988	34	0.934
18	1.083	27	0.979	35	0.930
19	1.070	28	0.971	40	0.894
20	1.056	29	0.963	45	0.874
21	1.042				

NOTE—This table is based on nominal 1.215 specific gravity cells. For cells with other specific gravities, refer to the manufacturer. Manufacturers recommend that battery testing be performed between 18°C and 32°C. See Annex L for the Fahrenheit conversion for Table 2.

7.3.2.2 Rate-adjusted capacity determination

To calculate the percent capacity for this test method, it is necessary to consult the manufacturer's data to determine the published rating for the actual time of the test to the specified terminal voltage. The battery capacity is then calculated using the following formula:

$$\%\text{ capacity at } 25\ °\text{C} = \frac{X_a \times K_C}{X_t} \times 100$$

where

X_a = actual rate used for the test,
X_t = published rating for time *t*,
t = time of test to specified terminal voltage [see 7.4, item c)],
K_c = temperature correction factor (see Table 2).

Rates can be in either amps or watts. See Annex K for an example of this method.

The previous capacity evaluation method should not be applied to an acceptance test unless a minimum of 100% capacity was required by the purchase specifications. If 90% capacity on delivery is acceptable to the user, the battery should demonstrate that it can provide at least 90% of the manufacturer's rated time for the selected discharge rate.

7.4 Acceptance, modified performance, and performance tests

a) Set up a load and the necessary instrumentation to maintain the test discharge rate determined in 7.3.

b) Disconnect the charging source, connect the load bank to the battery, start the timing, and continue to maintain the selected discharge rate. If the charging source cannot be disconnected, the current being drawn by the load must be increased to compensate for the current being supplied by the charging source to the battery.

c) Maintain the discharge rate until the battery terminal voltage decreases to a value equal to the minimum average voltage per cell as specified by the design of the installation times the number of cells. For acceptance and performance tests as an example, a 60 cell battery with a minimum design voltage of 1.75 volts per cell, then the minimum battery voltage for the test is 60 × 1.75 or 105 volts. For a modified performance test, see Annex I to determine the terminal voltage.

d) Read and record the individual cell voltages and the battery terminal voltage. The measurements should be taken while the load is applied at the beginning of the test, at specified intervals, and at the completion of the test. There should be a minimum of three sets of measurements.

    1) Individual cell voltage measurements should be taken between respective posts of like polarity of adjacent cells, so as to include the voltage drop of the intercell connectors.

    2) The possibility of a weak cell(s) should be anticipated and preparations should be made for bypassing the weak cell with minimum hazard to personnel for performance testing only.

e) If one or more cells is approaching reversal of its polarity (+1.0 V or less) and the test nears the 90 to 95% expected completion time, continue the test until the specified terminal voltage is reached.

f) If earlier in the test, an individual cell is approaching reversal of its polarity (plus 1 V or less), but the terminal voltage has not yet reached its test limit, the test should be stopped, and the weak cell should be disconnected from the battery string and bypassed with a jumper of adequate conductor ampacity. The new minimum terminal voltage should be determined based on the remaining cells [see 7.4, item c)]. The test should then be continued in order to determine the capacity of the remaining cells. The time required to disconnect the cell, install the jumper, and restart the test shall not exceed 10% of the total test duration or 6 minutes, whichever is shorter. This "downtime" shall not be included in the test discharge period (i.e., the capacity determination shall be based on the actual test time). No more than one "downtime" period should be allowed when a battery is being tested. The battery may supply higher than its normal capacity (especially during short duration testing) if the battery is subjected to more than one "downtime" period.

g) In the event of problems with the load bank that interrupts the test, the test should be continued in order to determine the capacity of the remaining cells. The time of the interruption shall not exceed 10% of the total test duration or 6 minutes, whichever is shorter. This "downtime" shall not be included in the test discharge period. No more than one "downtime" period should be allowed when a battery is being tested. The battery may supply higher than its normal capacity (especially during short duration testing) if the battery is subjected to more than one "downtime" period.

h) Observe the battery for abnormal intercell connector heating.

i) At the conclusion of the test, determine the battery capacity according to the procedure outlined in 7.3.

If, after the test, one or more of the cells are replaced, the benchmark capacity of the battery can be reestablished by either retesting the battery or by analysis. If the problem is identified and corrected, the cell can be reinstalled into the battery and the battery retested to establish the benchmark capacity, or the cell can be discharged independently, recharged, reinstalled into the bank, and the benchmark capacity reestablished by analysis (see 7.3.1 or 7.3.2).

7.5 Service test

A service test is a special battery discharge test that may be required to determine if the battery will meet the battery duty cycle (see 6.3). The system designer should establish the test procedure and acceptance criteria prior to the test. The battery should be tested in its "as found" condition and the test should not be corrected for temperature or age. If the battery was sized in accordance with IEEE Std 485-1997, the margins added for temperature ranges, load growth, and aging will provide adequate battery capacity to meet the battery duty cycle throughout its service life. Trending battery voltage during the critical periods of the 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 (IEEE Std 485-1997) should be reviewed, and the service test modified accordingly. Successful test results can be used to evaluate battery performance and degradation. The recommended procedure for the test is as follows:

a) The initial conditions shall be as identified in 7.1, omitting requirement a) of 7.1. When performing requirement b) of 7.1, take no corrective action unless there is a hazard to personnel safety or the possibility of permanent damage to the battery.

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

c) If the battery does not meet the duty cycle, review its rating to see if it is properly sized; equalize the battery, and, if necessary, inspect the battery as discussed in 5.2.4; take necessary corrective actions as discussed in 5.3; and repeat the service test. A battery performance test (see 6.2) may also be required to determine whether the problem is the battery or the application.

7.6 Restoration

Disconnect all test apparatus. Recharge the battery and return it to normal service.

8. Battery replacement criteria

The recommended practice is to replace the battery if its capacity as determined in 7.3 is below 80% of the manufacturer's rating. After completion of a capacity test, the user should review the sizing criteria to determine if the remaining capacity is sufficient for the battery to perform its intended function. The timing of the replacement is a function of the sizing criteria utilized and the capacity margin, compared to the load requirements available. Whenever replacement is required, the recommended maximum time for replacement is one year.

It should be noted that if capacity was calculated using the rate-adjusted method per 7.3.2 and capacity has fallen to 80%, the one-year replacement period might not ensure that the battery can fulfill its duty cycle. In this instance, the battery should be replaced at the earliest opportunity.

A capacity of 80% shows that the battery rate of deterioration is increasing even if there is ample capacity to meet the load requirements. Other factors, such as unsatisfactory battery service test results (see 7.5), require battery replacement unless a satisfactory service test can be obtained following corrective actions.

Due to changes in battery design, materials, and technology, the battery manufacturer should be contacted for the latest information for the replacement battery. Also, prior to selecting the replacement battery, it is prudent to review the battery sizing calculation per IEEE Std 485-1997 to ensure the calculation is still valid for the new battery's characteristics and any load changes.

Physical characteristics, such as plate condition together with age, are often determinants for complete battery or individual cell replacements. Reversal of a cell, as described in item e) of 7.4, is also a good indicator for further investigation into the need for individual cell replacement. Replacement cells, if used, should be compatible with existing cells and should be tested in accordance with 6.1 of this recommended practice and installed in accordance with IEEE Std 484-1996. The capacity of the replacement cell(s) should not degrade the battery's existing ability to meet its duty cycle. Replacement cells are not usually recommended as the battery nears its end of life. Due to material and/or design changes, cells of different vintages may have different operating characteristics. Identical model numbers do not guarantee compatibility. Before mixing cells of different vintages, contact the manufacturer.

Failure to hold a charge, as shown by cell voltage and specific gravity measurements, is a good indicator for further investigation into the need for battery replacement.

When disposing of a battery, refer to Clause 10 of this standard.

9. Records

The analysis of data obtained from inspections and corrective actions is important to the operation and life of the batteries. 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 on capacity and other tests indicating the discharge rates, their duration, and results.

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.

10. Recycling and disposal

All batteries have a useful life and eventually must be scrapped. Therefore, a lead-acid battery that must be scrapped shall be disposed of in a proper fashion.

10.1 Recycling

The preferred method of scrapping a lead-acid battery is recycling. Seek advice from the battery manufacturer or distributor on how to proceed with battery recycling.

10.2 Disposal

When a battery is to be disposed of, governmental regulations for such disposal shall be followed. Local agencies, such as a hazardous waste management agency, can provide the user with proper disposal methods and requirements.

Annex A

(informative)

State of charge

A.1 Battery discharge/charge cycle parameters

The most accurate method of returning a battery to full charge following a discharge is to assure greater than 100% of the amp-hours removed are returned to the battery, allowing for losses due to hydrogen generation and heat generated. A 10% estimate is conservatively used for losses for a total of 110% of the discharge amp hours. The charging method can affect the time that it takes to restore the battery to full charge. Constant voltage charging effectiveness is dependent on the length of time the charger remains in current limit and the value of the charging current after it stabilizes. If the charging voltage is low the charger will come out of current limit sooner reducing the rate at which amp-hours returned to the battery. Additionally, the level of current at float voltage may be below a detectable level, which assures that charging current is not dropping and has stabilized. Charging at a voltage above float results in a positive indication that current stability has been achieved. For low-voltage charging systems, cumulative amp-hours should be considered as an indicator of return of the battery to the fully charged state.

Inadequate voltage during the charge process can lead to a cell that cannot repeat its previous performance. The resulting battery will yield a lower capacity than its last performance test. Low charging voltage leads to reduced time for the charger at current limit and results in an extended charging period to return the required amp-hours. Normal electrolyte temperatures are preferred for charging a battery; low temperatures will reduce the current drawn, slow the charging process, and the low current measurements may also yield misleading indications of a fully charged state. The manufacturer should be consulted for the proper recharge voltage, temperature, and the expected duration of recharge. Low stable charge current is a consistent indicator at adequate charging voltage and normal temperatures.

A.2 Stabilized charging current used to determine a fully charged condition

The pattern of charging current delivered by a conventional voltage-regulated charger after a discharge is the most accurate method for 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 for three consecutive hourly measurements, the battery is near full charge. The expected charging current range applicable to each model may be verified by test or in consultation with the manufacturer.

If the charging voltage has been set at a value higher than normal float voltage (so as to assure proper charging and reduce charging time), the charging voltage can be reduced to the float value after the charging current stabilizes. The float current will soon stabilize, even though the specific gravity measurements at the top of the cell continue to increase.

Chemical changes within the battery due to the aging process may result in unequal charging of the negative and positive plates. In such cases the positive plate (or the negative) may sulfate due to low charging current. Visual inspections should be performed as a supplement to the use of float current.

NOTE—Refer to the individual manufacturer's instructions for time periods to maintain charging voltages after current stabilization.

A.3 Electrolyte specific gravity used to determine a fully charged condition

Specific gravity (S.G.) is defined as the density of a liquid at a selected reference temperature [e.g., 25 °C (77 °F)] divided by the density of water at the same temperature. When measuring the electrolyte specific gravity, a reference temperature of 25 °C (77 °F) is typically utilized for lead-acid cells with a nominal specific gravity range from 1.210–1.300.

A fully charged lead-acid cell has an open circuit voltage (OCV) in the range of 2.05 to 2.15 V. The OCV varies with both temperature and electrolyte specific gravity. The relationship of OCV to specific gravity is: OCV = S.G. + 0.845

The float voltage for a battery is usually set to overcome a cell's tendency to self-discharge.

The electrolyte participates in the battery chemical reaction to produce current. When a cell discharges, the sulfuric acid combines with lead dioxide from the positive plates and lead from the negative plates to form lead sulfate in the plates and water in the electrolyte.

During discharge, the electrolyte sulfuric acid concentration and specific gravity decrease. Conversely, during recharge, the sulfuric acid concentration and specific gravity increase.

Based on the interaction between cell plates and electrolyte, a low specific gravity measurement typically indicates a cell is not fully charged, which may require corrective action (e.g., recharge) to restore specific gravity to the expected range.

Specific gravity measurements may not be accurate when the battery is on charge following a discharge or following the addition of water. (Highest electrolyte specific gravity at the bottom of the cell, lowest at the top.) When cell design permits, specific gravity measurement accuracy can be improved by taking measurements at the top, middle, and bottom of the cell. The average of these three measurements should reflect the actual electrolyte specific gravity of a cell.

An adequate specific gravity value does indicate a fully charged cell, but does not indicate a fully capable cell. Specific gravity measurements are a good maintenance tool to check for proper battery charger performance and battery state of charge.

A.4 State of charge/Choosing float current

Some methods for determining the state of charge are better suited for certain plate metallurgies than others. Therefore, the type of cells (e.g., lead-calcium, pure lead, or lead-antimony) comprising the battery system is a factor in selecting inspection procedures for determining the state of charge.

Stationary batteries are normally kept fully charged at a potential, which supplies enough current to replace internal losses and keep the plates at an optimum state of polarization (charge). The positive plates of the cell use some of this current to produce oxygen and to corrode the grid metal; and the negative plates use some of this current to produce hydrogen and to reduce oxygen that diffuses from the positive plates.

The amount of hydrogen liberated, and thus, the amount of water the battery will consume, are functions of the charging current. In practical terms, cells with lead-antimony grids will require more charging current to maintain a given voltage than cells with lead-calcium or pure lead grids.

Float charge current and gas evolution are proportional to the antimony content of the grids. Furthermore, as antimony grids age, they release increasing amounts of antimony to the electrolyte, which then migrates to the negative plate to form local cells and a subsequent self-discharge, which must be compensated for by increasing the charging current. Calcium, unlike antimony, does not migrate from the positive grid to the negative plate, so the negative electrode remains essentially pure, and the required charging current remains constant over its service life.

Float charging current is a useful indicator of battery condition when the battery cells have constant float charging characteristics throughout their service life. (e.g., cells with pure lead or lead-calcium plates). In cells requiring additional charging current as they age, such as lead-antimony, this assessment is more difficult to make.

The higher charging currents required for lead-antimony cells results in a fundamentally tight voltage distribution among the cells; whereas, the low charging current required by lead-calcium cells often results in a wider voltage variation between cells, making the pilot cell float voltage measurements less reliable as an indicator of state of charge.

The higher gas evolution rates of lead-antimony cells also makes their specific gravity measurements a good indicator of the condition of the cells. The low rates of gas evolution in lead-calcium and pure lead cells means the electrolyte is slow to diffuse after charging or water additions and an accurate indication of the cells' condition may not be available for several months. Therefore, for cells with lead antimony plates it is recommended to measure the float voltage and the specific gravity of the cells in order to characterize the state of charge.

It should be noted that for the purposes of the preceding discussion, *lead-antimony* refers to designs in which the antimony content in the positive grid alloy is greater than 2%. Low-antimony designs, such as lead-selenium that contain less than 2% antimony, share many of the charging characteristics of lead-calcium types, including a low, stable float current.

Annex B

(informative)

Specific gravity

B.1 Effect of charging

During the recharge of a battery, high-specific-gravity sulfuric acid is generated. This acid will sink toward the bottom of the cell, resulting in a specific gravity gradient that produces a low value at the top of the cell that is not representative of the average specific gravity (S.G.). Therefore it is normal for the state of charge as indicated by the S.G. of electrolyte at the top of the cell to lag behind the state of charge that is indicated by the ampere-hours returned to the battery indicated by reduced current to the battery on recharge. Charging voltage limits do not ordinarily allow enough gassing during recharge to provide mixing action. Therefore this gradient may persist until corrected by diffusion. This S.G. gradient will gradually disappear on float charge over time.

B.2 Effect of temperature

S.G. values are based on a temperature of 25 °C (77 °F). The values should be corrected for the actual electrolyte temperature and level (see B.3). For each 1.67 °C (3 °F) above 25 °C (77 °F) add 1 point (0.001) to the value. Subtract 1 point for each 1.67 °C (3 °F) below 25 °C (77 °F).

B.3 Effect of electrolyte level

The S.G. of the electrolyte in a cell will increase with a loss of water due to electrolysis or evaporation. When S.G. measurements are being taken, the electrolyte levels should also be measured and recorded. The battery manufacturer will provide a S.G. correction factor for the particular cells involved. However, if the electrolyte level is between the high- and low-level marks and the temperature corrected S.G. of the electrolyte is within the manufacturer’s nominal S.G. range, it is not necessary to correct the S.G. of the battery for electrolyte level.

The apparent electrolyte level depends on the charging rate because gas generated during charging causes an apparent expansion of the electrolyte. If the electrolyte is at or near the high-level mark at float voltage, it may rise above that mark on charge. This condition is not objectionable.

B.4 Effect of water additions

When water is added to a cell, it tends to float on top of the electrolyte because its S.G. is 1.000 in comparison to 1.215 nominal for the electrolyte in most batteries. If the cells are in a normal float-charge condition, there is very little mixing of the electrolyte due to gassing. In certain cell types, it may take 6 to 8 weeks or longer for complete mixing to occur. The S.G. should be read before adding water.

Annex C

(informative)

Float voltage

C.1 Low-voltage cells

Cell voltage is not, by itself, an indication of the state of charge of the battery. Prolonged operation of cells below 2.13 V (typical for nominal 1.215 S.G. cells) can reduce the life expectancy of cells. If normal life is to be obtained from these cells, they should be given an equalizing charge. (Consult the manufacturer for the proper voltage values for other values of S.G.)

NOTE—A cell voltage of 2.07 V (typical for nominal 1.215 S.G. cells) or below under float conditions and not caused by elevated temperature of the cell indicates internal cell problems and may require cell replacement. (Consult the manufacturer for the proper voltage values for other values of S.G.)

C.2 High-voltage cells

Normally, there is no detrimental effect associated with a cell that has a float voltage slightly higher than the average of the other cells in the battery. However, when a cell's voltage is significantly higher [0.1 volts for a pure-lead/lead-calcium cell or 0.05 volts for a lead-antimony/lead-selenium cell] than the average, the cause should be investigated and corrected if necessary. This condition could be caused by a number of factors, including the following:

1) Abnormal specific gravity in the cell
2) Mixing cells of different ages
3) Mixing cells of different types
4) Changes in the design or the cell materials
5) Defective cells

NOTE—Contact the manufacturer for information and possible corrective actions.

C.3 Effect of temperature

As the temperature of the electrolyte increases, the internal resistance decreases and the electrochemical reaction rates increase requiring the charging current to increase in order to maintain a constant cell voltage. Therefore, cells in a battery at a higher temperature than the other cells will require higher current. However, as the cells are in series, the charger voltage and the average electrolyte temperature of the battery determine the current. The voltage of the warmer cells will be lower than the average.

If a warmer cell's voltage is below 2.13 V, its temperature-corrected voltage can be determined by adding 0.003 V for each degree Fahrenheit (0.005 V/°C) that the cell temperature is above the average temperature of the other cells. If the cell voltage is less than 2.13 V after being corrected for the effects of temperature, an equalizing charge is required. An effort should be made to eliminate the cause of the temperature differential. (Refer to C.1 and D.3.)

When all cells are at some higher temperature, the charging current under normal float conditions will automatically increase to hold the required float voltage. However, individual cell voltages will not be affected and no correction for temperature will be necessary.

Low temperatures have the opposite effect on cell chemistry.

Annex D

(informative)

Urgency of corrective actions

D.1 Adding water

For capacity, the addition of water is not urgent unless the tops of the plates are in danger of being exposed. However, for safety, if flame-arresting vents are provided, water should be added before the electrolyte level reaches the bottom of the funnel stem. Electrolyte levels above the high-level line will not affect safety or capacity unless the cell reaches an electrolyte overflow condition.

If the level of electrolyte has dropped low enough to expose plates, check the S.G. where possible and then add water to at least the low-level line. If visual inspection shows no evidence of leakage, then perform an equalize charge. Following the equalize charge, inspect for sulfation near the top of the negative plate and for loss of active material of the positive plate. If any of these conditions exist, the user should consider additional corrective actions, which may include replacing the cell(s). The manufacturer should be contacted for further guidance on cell recovery or replacement.

D.2 Connection resistance

It is good practice to read and record intercell and terminal connection resistances as a baseline upon installation as recommended by IEEE Std 484-1996. 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 connection resistance varies with the cell size and connection type. The following methods may be used to establish a connection resistance limit, which should initiate corrective action prior to the next inspection:

a) The manufacturer may be contacted to provide a recommended action limit.

b) Baseline value may be established by measuring the connections after initial installation or after a cleaning of the connections. A 20% increase from a baseline value may serve as a criterion for initiation of corrective action prior to the next inspection. Note that base line values are specific to each connection and not an average of all connections.

c) The manufacturer may be contacted for the expected baseline values. A 20% increase in the manufacturer’s expected baseline value may serve as the action limit.

d) The design maximum for the connection resistance may be calculated using either specific or generic manufacturer’s connection voltage drop criterion. Strap connections are typically designed for a 20 to 30 milli-volt drop. The maximum connection resistance for a generic criteria of 20 millivolts can be calculated using $V = IR$. The current (I) should be equal to a current that bounds the continuous current in the duty cycle. Typically the performance test current rate bounds the continuous current in the duty cycle. Under these conditions, I would equal the performance test rate and $V =$ .020 volts. Solve $R = V/I$ for the maximum connection resistance.

The timing of the corrective action for increased connection resistance should be determined by an analysis of the effects of the increased resistance. Since option d), above, establishes a value near the design limit, the timeliness of the action may be more critical than with options a), b), or c). Excessive acid wicking to the connection or spillage from above cells may result in approaching the connection resistance limits rapidly. See Annex F for the suggested methods of measuring connection resistances.

Whenever all battery connections are cleaned and reassembled, a new baseline should be established. If the baseline information for an installed battery is unknown, then a baseline should be established when all connections are cleaned and reassembled. When establishing a baseline, the resistance measurements for the entire battery should be taken and if any connection is

1) Greater than 20% above the average of the measurements or
2) Greater than 5 microohms above the average, if 5 microohms is greater than 20% of the average, then the connection(s) should be retorqued and retested.

If retested resistance value remains unacceptable, the connection should be disassembled, cleaned, reassembled, and retested.

D.3 Cell temperature

Large cell-temperature deviations are usually caused by shorting conditions, which are also evident by abnormal cell voltage and/or increasing float current. This is cause for immediate cell replacement. All other temperature deviations are usually caused by outside conditions that are part of the installation [see IEEE Std 484-1996, 5.1.1(5)]. While operation at elevated temperatures will reduce life expectancy, it will not adversely affect capacity.

D.4 Equalizing charge

When an individual cell voltage corrected for temperature is below 2.13 V, (typical for nominal 1.215 S.G. cells) or the specific gravity corrected for temperature falls below the manufacturer's limit, corrective action should be initiated. It can be accomplished by providing an equalizing charge to the entire battery. However, it is often more convenient to apply the equalizing charge to the individual cell. This may be done during normal float operation of the battery.

Annex E

(informative)

Visual inspection of battery installations

The following is a list of visual parameters that can be used to inspect a battery while it is in service. It is important that all abnormalities and all other observations made during the inspection (whether good or bad) be recorded. This information can be used for trending purposes in the future.

a) Inspect the battery rack/cabinet and anchors for rusting, corrosion, and other deterioration that could affect the battery rack structural or seismic integrity and strength and inspect approximately 10% of the battery rack fasteners for tightness.

b) Perform the following steps where applicable for seismic installations.
   1) Inspect the battery to ensure an intercell spacer is present between each battery jar.
   2) Inspect the intercell spacers in place for deterioration (broken, warped, crumbling, etc.).
   3) Verify that the space between each of the end-rails and the end battery jars is less than or equal to 3/16” or a value specified by the manufacturer.

c) Verify that the rail insulators are in place and in good condition.

d) Verify that the electrolyte level of each cell is between the high- and low-level marks imprinted on the cell case.

e) Inspect each battery cell jar, cell jar cover, and seals (jar to cover seal, post to cover seal) for deterioration (acid leakage, cracking, crazing-spiderweb effect, distortion, etc.).

f) Examine the plates in each cell for sulfation.

NOTE—Sulfation can sometimes be detected on the plate edges by shining a light source on the plates, which will reflect off the yellowish sulfate crystals.

g) Examine the plates in each cell for the proper color that indicates a fully charged battery based on the manufacturer’s information.

NOTE—Normally, fully-charged, positive plates are colored a deep chocolate-brown color. Negative plates are normally a medium gray. A horizontal ring of white deposits around the plates and on the inside of the jar indicates hydration. This is a result of the lead sulfate precipitating out of solution after the recharge of an over discharged cell or the recharge of a discharged cell that has not been promptly recharged. Consult your manufacturer’s maintenance instructions for further guidelines in this area. If any negative plates are reddish in color, this indicates copper contamination, and the cell should be replaced as soon as practical.

h) Examine, if possible through the clear battery jar case, the plates, bus bar connection to each plate, and bus bar connection to the post of each battery cell for corrosion and other abnormalities. Inspect the lower part of the post seals and the underside of the cover for cracking or distortion.

i) Examine the cell plates, spacers, and sediment space of each cell to determine if any deterioration (warped plates and spacers, lifted cell posts, pieces of plate material that have fallen off, shorted plates, excessive sediment in the bottom of the cell, plates that have dropped lower than the other plates, etc.) has occurred that could affect a cell relative to the rest of the cells in the battery.

j) Examine the cell posts of each cell to determine if any of them have grown or lifted to a larger degree than the rest of the posts of the battery.

NOTE— The positive plates of lead-acid batteries normally swell or grow with age and use. Most manufacturer’s claim that 5% growth is the expected maximum limit during the life of the battery.

k) Inspect each electrical cell-to-cell and terminal connection to ensure they are clean (no significant corrosion or foreign matter) and the connection surfaces are coated with a thin layer of anti-corrosion material.

NOTE—Unless corrosion is cleaned off of battery terminals periodically, it will spread into the area between the posts and the connectors.

l) Verify that all cells of the battery are properly numbered.

m) Verify that each battery cell vent, flame arrestors, and dust caps are present and inspect each for damage.

n) Examine the general condition of the battery, battery rack and/or cabinet, and the battery room to determine if they are clean and in good order.

Annex F

(informative)

Examples of methods for performing connection resistance measurements using a microohmmeter

The following are examples of how to take intercell connection resistance measurements for a variety of available battery designs. Other battery designs and methods for taking resistance measurements are also used but not specified in this annex. It is important to select a method for a particular battery design and use the same method consistently for trending purposes.

F.1 Recommended method for performing connection resistance measurements using a microohmmeter

a) When taking microohmmeter measurements, the probes should be held perpendicular to the battery post.

b) Set the microohmmeter scale to the lowest resistance scale.

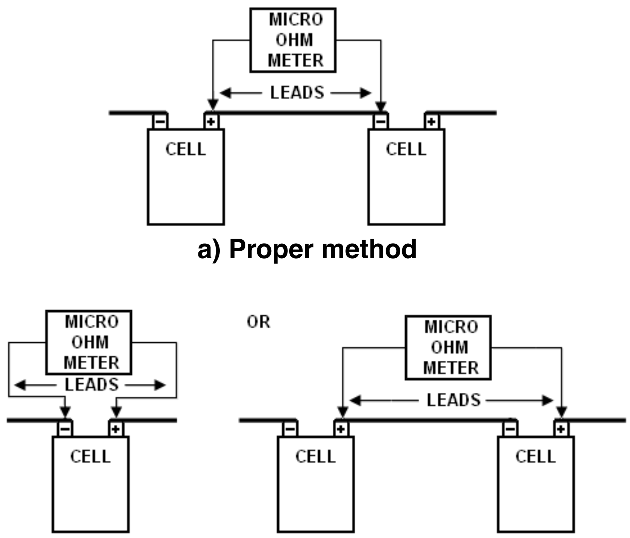
WARNING

DO NOT TAKE MEASUREMENTS ACROSS THE CELL. THIS IMPROPER ACTION COULD CAUSE PERSONAL INJURY, DAMAGE TO THE TEST EQUIPMENT, AND DAMAGE THE CELL.

c) When performing microohmmeter measurements, it is recommended to take these measurements from the battery post to battery post of connected cells, or from the battery post to the terminal Lug.

NOTE—It is not acceptable to record the measurements in milliohms. All measurements must be converted into microohms.

The proper and improper methods of performing connection resistance measurements are shown in Figure F.1a) and Figure F.1b) respectively.



b) Improper methods

Figure F.1—Connection resistance measurements

F.2 Recommended method for single intercell connections and parallel-post connections

a) MEASURE the intercell connection resistance of each intercell connection by measuring from the positive terminal post to the negative terminal post of the adjacent cell.

b) RECORD the measurements.

Single intercell connections and parallel-post intercell connection resistance measurements are treated in the same manner.

Figure F.2 shows a typical single intercell connection. Figure F.3 shows a typical parallel-post intercell connection.

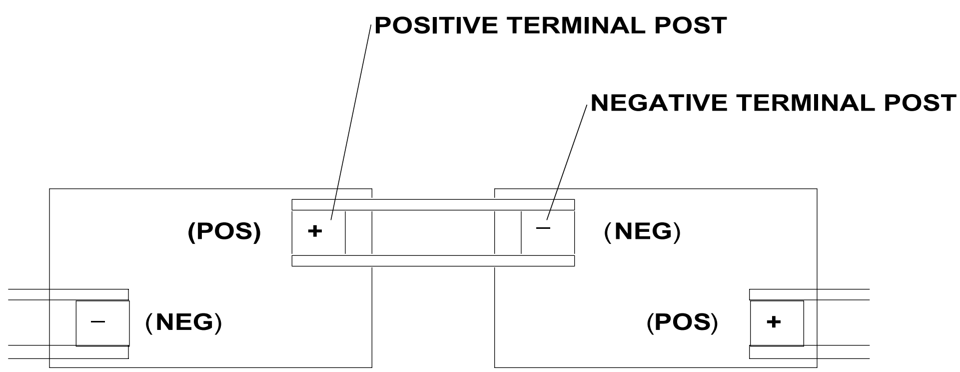


Figure F.2—Single intercell connection (typical)

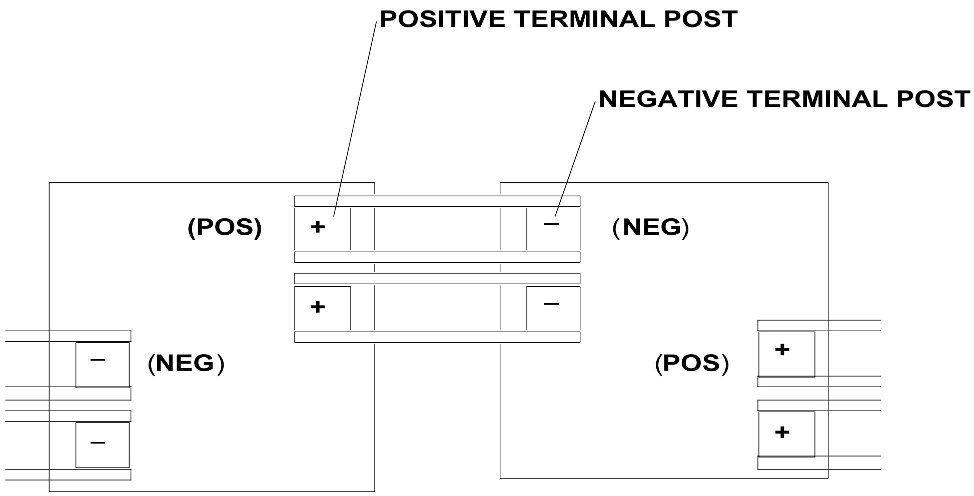


Figure F.3—Parallel-post Intercell connection (typical)

F.3 Recommended method for double-post intercell connections

a) MEASURE the intercell connection resistance of each intercell connection by measuring from:
   1) Terminal Post A to Terminal Post C
   2) Terminal Post B to Terminal Post D

b) RECORD the measurements.

The resistance of inter-tier and inter-rack connections, with or without connection plates, can be performed using steps a) and b) listed above.

Figure F.4 shows a typical double-post intercell connection.

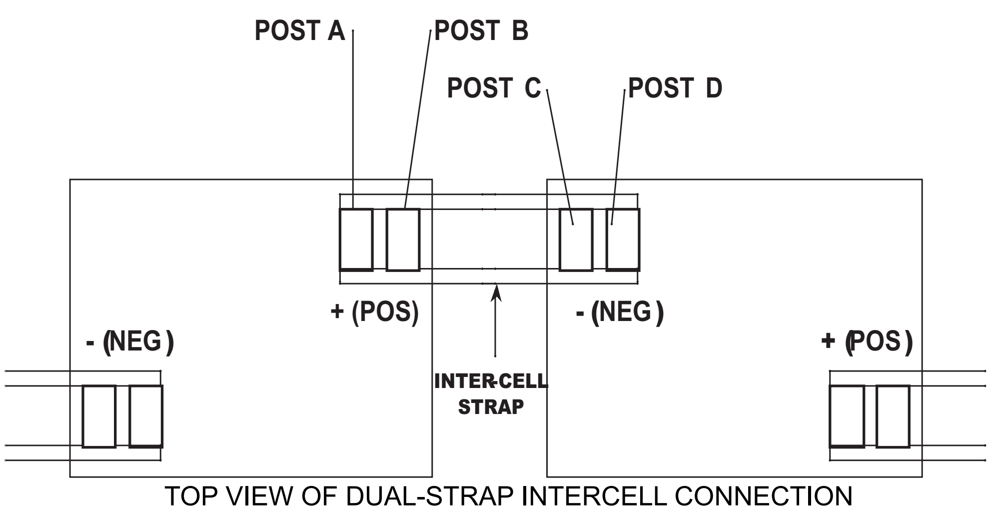


Figure F.4—Double-post intercell connection (typical)

F.4 Recommended method for triple-post intercell connections

a) MEASURE the intercell connection resistance of each intercell connection by measuring from:
   1) Terminal Post A to Terminal Post D
   2) Terminal Post B to Terminal Post E
   3) Terminal Post C to Terminal Post F
b) RECORD the measurements.

The resistance of inter-tier and inter-rack connections, with or without connection plates, can be performed using steps a) and b) listed above.

Figure F.5 shows a typical triple-post intercell connection.

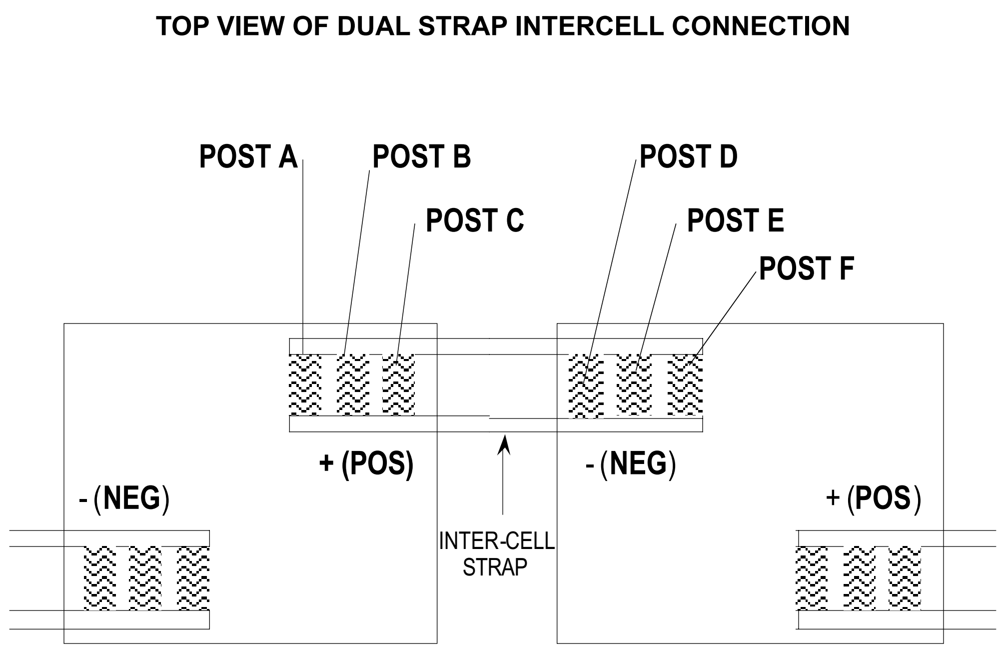
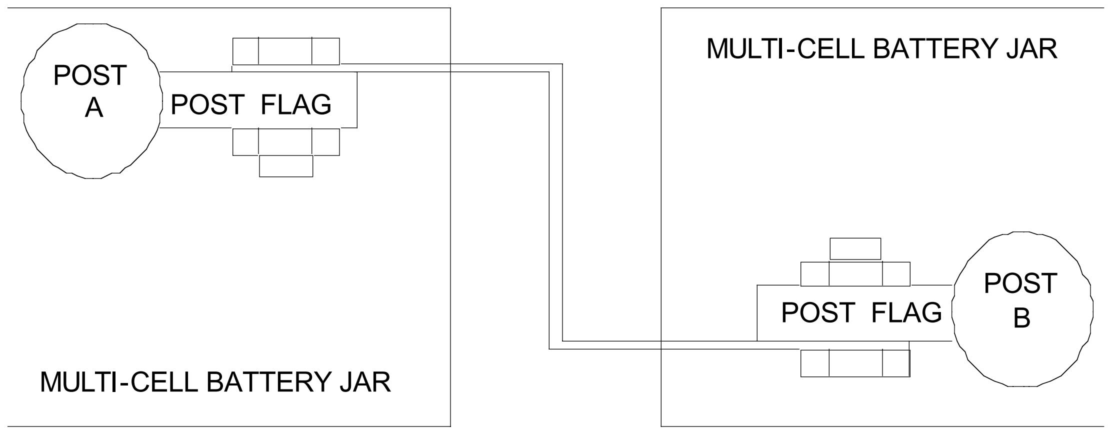


Figure F.5—Triple-post intercell connection (typical)

F.5 Recommended method for flag-post intercell connections

a) MEASURE the connection resistance of the intercell connections from terminal post A to terminal post B.
b) MEASURE the connection resistance of the inter-tier and inter-rack from terminal post A to post B and/or from post A to Lug A and post B to Lug B terminal.
c) MEASURE the connection resistance of the Terminal connections from Post to the Lug A on the connecting cable.
d) RECORD the measurements.

Figure F.6 Shows typical post-flag terminal connections.



Z Bar or Cable

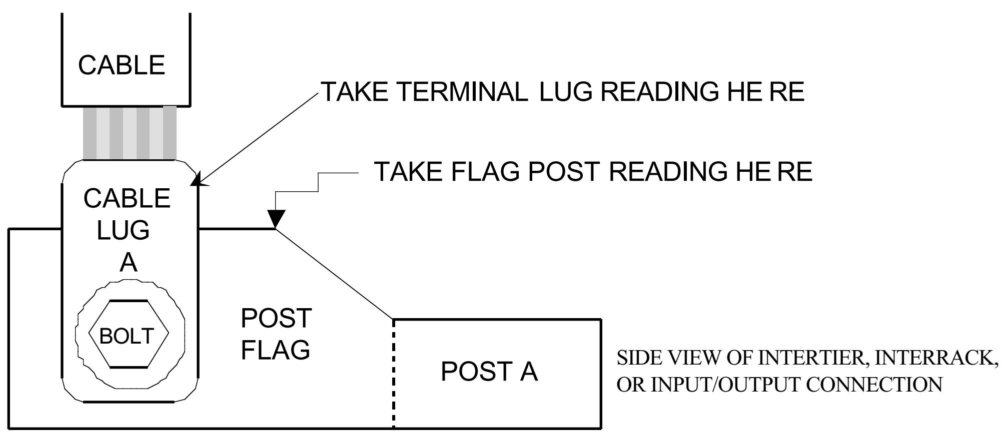


Figure F.6—Post-flag terminal connections (typical)

F.6 Recommend method for single connections

a) MEASURE the terminal connection resistance of single terminal connections by measuring from terminal lug to terminal post.

b) RECORD the measurements.

Figure F.7 shows a typical single terminal connection.

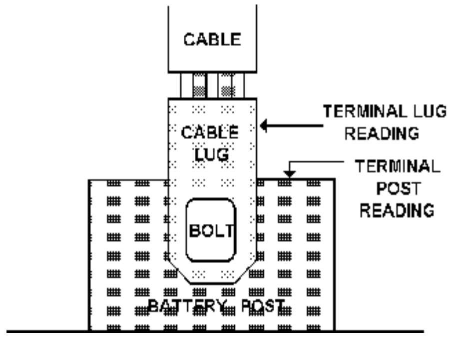


Figure F.7—Single terminal connection (typical)

F.7 Recommended method for multiple terminal connections

a) MEASURE the terminal connection resistance of each terminal connection by measuring from:
   1) Terminal Lug A to Terminal Post A
   2) Terminal Lug B to Terminal Post B

b) RECORD the measurements.

Figure F.8 shows a typical multiple terminal connection.

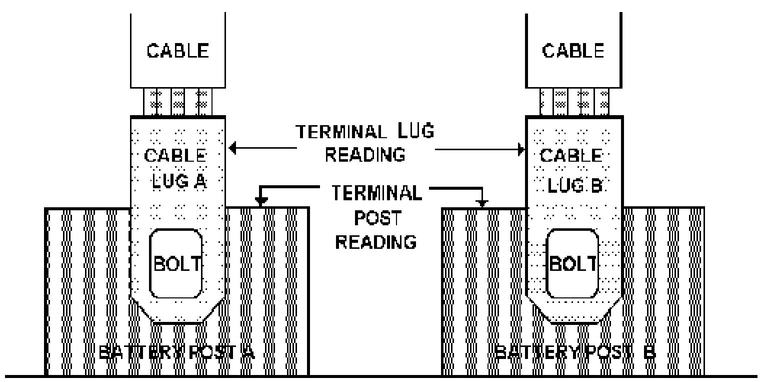


Figure F.8—Multiple terminal connection (typical)

F.8 Recommended method for cable-plate-post connections

a) MEASURE the resistance of each terminal connection by measuring from:
   1) Terminal Lug A to Terminal Post A
   2) Terminal Lug B to Terminal Post A
   3) Terminal Lug C to Terminal Post B
   4) Terminal Lug D to Terminal Post A

5) Terminal Lug E to Terminal Post B
6) Terminal Lug F to Terminal Post B

b) RECORD the measurements.

The resistance of inter-rack connections and terminal connections will be performed using steps a) and b).

Figure F.9 shows a typical cable-plate-post connection.

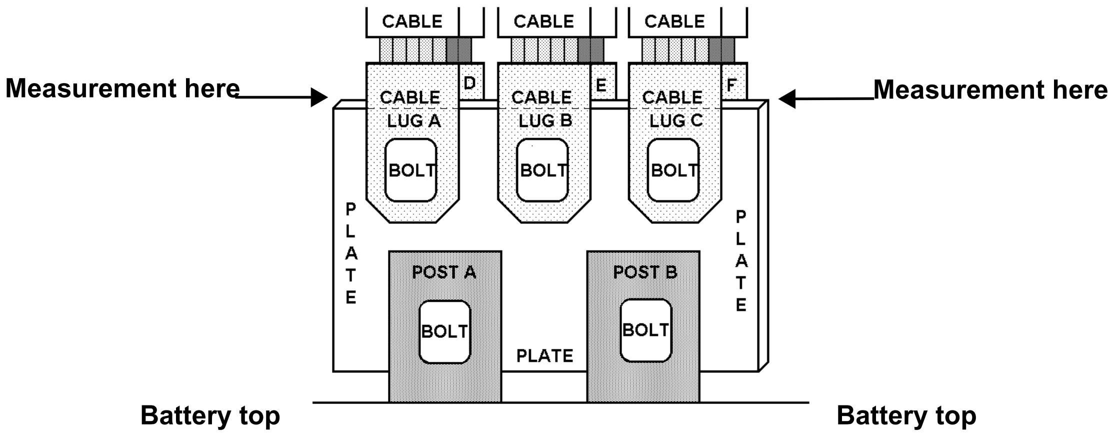


Figure F.9—Cable-plate-post connection (typical)

The lug on the other side of plate from Lug A is marked as Lug D, Lug B as Lug E, and Lug C as Lug F.

Annex G

(informative)

Alternate applications

The recommendations for periodic inspections and subsequent corrective actions are intended to provide a well-maintained battery that will meet its performance requirements. The recommendations for periodic performance/service type tests are intended to provide an immediate demonstration of battery capability, and the adequacy of the maintenance practices. Trending periodic test results will often allow the user to predict when battery replacement will be necessary. Each of these recommended practices of inspections and tests should be used as best suited for the particular needs of the application. It is the user's responsibility to format the maintenance, inspection, and testing program to optimize benefits available.

All of these recommendations for maintenance and testing may not apply to all battery applications. For example, it may not be possible to inspect batteries installed in remote locations but once a year; or it may not be possible to take the battery "off line" in order to conduct performance, modified performance, or service tests. In the latter instance, some users may test just one representative cell and apply the results to all the remaining cells; while some users may perform a short high-rate discharge that is accomplished without removing the battery from service. Tests like these can also provide useful trends of the battery's adequacy and may reduce the need for other inspections and tests.

The user of alternative test methods is cautioned to consider the following:

a) Unless the test rate(s) and duration envelopes the actual load(s) and duration, adequacy of the battery's performance may not always be demonstrated.

b) The results of short-duration discharge tests will not predict long-duration performance, and vice versa.

c) At high rates of discharge, battery performance is generally limited by the ohmic value of the cells and their connections. Small changes in these values can result in a much larger change in reserve time.

Annex H

(informative)

Effects of elevated electrolyte temperatures on vented lead-acid batteries

Seldom does a battery remain at the same temperature throughout the entire year. The following formula integrates annual variations by calculating the months of aging at elevated temperatures versus months of life at normal [25 °C (77 °F)] temperature. When determining the number of intervals to be evaluated, the user should consider the maximum deviation in temperature. Intervals should be selected where the maximum deviation within the interval does not exceed 3°C. Use of intervals with larger temperature variations will result in a less accurate prediction of battery life.

$$Lt_c = \frac{M}{\frac{[1 \times \text{mos @ } T_1]}{\%\text{ Life}} + \frac{[1 \times \text{mos @ } T_2]}{\%\text{ Life}} + \ldots + \frac{[1 \times \text{mos @ } T_n]}{\%\text{ Life}}}$$

Where:

Lt_c	=	The temperature corrected years of battery life,
% Life	=	From supplied graph,
Mos. @ T_1	=	Number of months at temperature T_1,
M	=	Normal life expectancy of the battery in months.

NOTE—$T_1 + T_2 + T_3 \ldots. + T_n$ must equal 12 (1 year).

EXAMPLE

The electrolyte temperature at installation “Y” averages 91 °F for four months of the year, 86 °F for four months of the year, and 77 °F for four months of the year. The expected life was 20 years [M = 240 months].

$$Lt_c = \frac{240}{\frac{[1 \times 4]}{0.52} + \frac{[1 \times 4]}{0.65} + \frac{[1 \times 4]}{1}}$$

$$Lt_c = \frac{240}{7.69 + 6.14 + 4} \qquad \frac{240}{17.84} = 13.45 \text{ years}$$

The installation “Y” battery ages	7.69 months during its 4 months at 32.8 °C (91 °F),
	6.14 months during its 4 months at 30.0 °C (86 °F),
	4.0 months during its 4 months at 25.0 °C (77 °F),
It then ages an equivalent of	17.84 month per calendar year

If the user chooses to operate the battery at the elevated temperatures described in the example, then he can expect the design life of the battery to drop from 20 years to 13.45 years.

The Thermal Degradation Curve (Figure H.1) uses a widely accepted rule of thumb for lead-acid battery aging that is based on the Arrhenius equation.

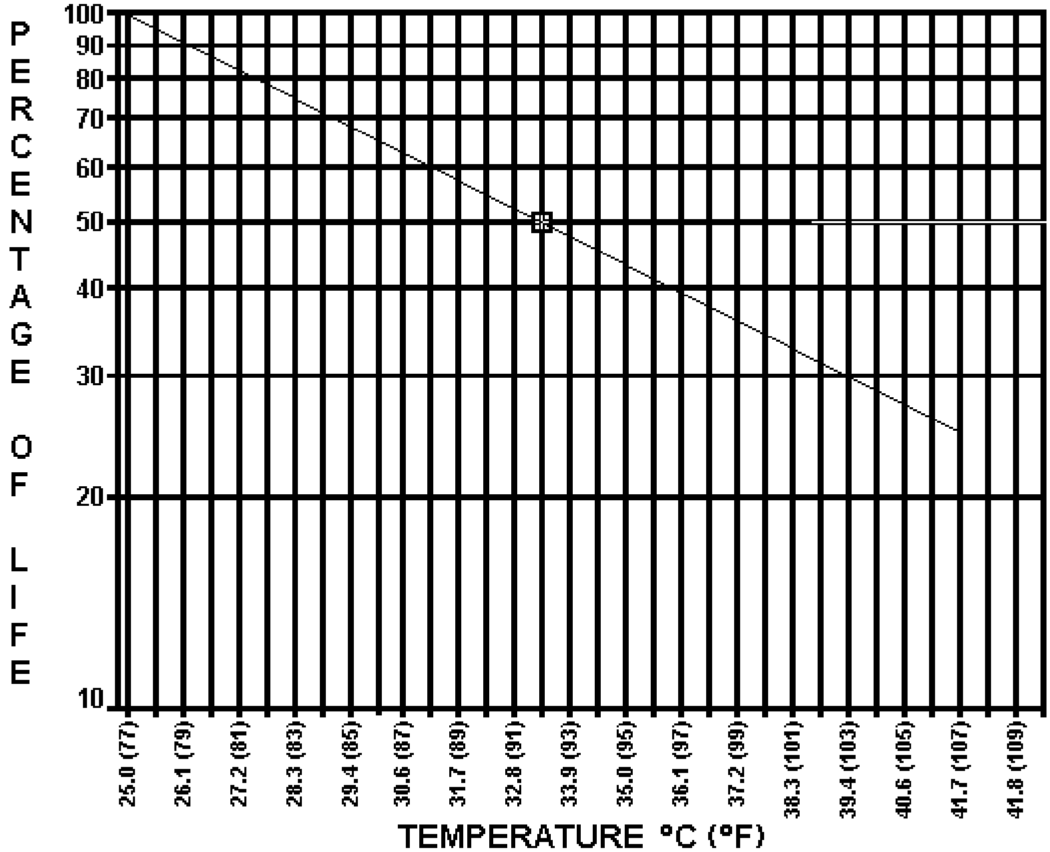


Figure H.1—Thermal degradation curve for lead-calcium batteries battery life vs. average battery temperature

Annex I

(normative)

Modified performance testing methods and examples

OBJECTIVES

A modified performance test (MPT) is a test of battery capacity, with the discharge rate(s) modified to encompass every portion of the battery duty cycle. This allows the performance test to be accomplished in the minimum amount of time while still demonstrating the high rate capability of the battery to meet the duty cycle requirements.

RULES FOR MODIFIED PERFORMANCE TESTS

To ensure that test envelopes the battery duty cycle throughout battery life, the minimum test duration is the duty cycle multiplied by the aging margin used in sizing the battery.

A MPT is ended when the battery terminal voltage drops to its minimum test voltage. During the portion of the test that envelopes the service test, the minimum voltage is the minimum voltage specified for the duty cycle. For the portion of the test that covers the aging margin, the minimum voltage can be reduced to match the manufacturer's capacity curves.

Current values are not adjusted for temperature. Temperature correction is applied during capacity calculation.

Three methods to perform this test are described in the subclauses that follow. For the best trending results, the same type of MPT should be used throughout battery life.

I.1 Type 1 modified performance test

This test comprises two rates; a short high-rate discharge followed by discharge at the normal rate for the performance test. Since the calculation method ignores the additional capacity removed during the high-rate discharge, that portion of the test is typically limited to a duration of 1 minute.

METHODOLOGY

1) Determine the value for the initial high-rate discharge. This is normally the largest current load of the battery duty cycle or the published 1 minute rate divided by the aging factor used in sizing the battery.
2) From the manufacturer's literature, determine the discharge rate for the time period specified for the entire duty cycle multiplied by the aging factor. Do not adjust this rate for temperature.
3) Set the first discharge time and rate for the value found in step 1). and the second discharge rate for the value found in step 2).
4) Record the battery terminal voltage just before the end of the high-rate discharge. After adjusting the load current to the second rate, follow the instructions in 7.4, steps c) though h). Note that if there is any interruption of the test before the duty cycle duration has elapsed, the requirements of the service test will not have been met.
5) Determine the capacity in accordance with 7.3.1.

EXAMPLE

This example assumes the installed battery has a 5 hour published rating of 400 amps and a 1 minute rating of 2720 amps. The duty cycle duration is 4 hours and the aging margin is 25%. Therefore the minimum test duration is 4 × 1.25 or 5 hours. Electrolyte temperature at the start of the test is 23°C.

Period	Duration of each step of duty cycle	Current for each step of duty cycle
1	0–60 seconds	1000.0 amperes
2	1–240 minutes	300 amperes

If the minimum battery voltage is reached after 308 minutes (including the first minute) and the temperature correction is .977 (from Table 1), the capacity is calculated as:

308/(300 × .977) × 100 = 105.1%

I.2 Type 2 modified performance test

This test is suitable for more complex duty cycles than the type 1 test. For the purposes of the methodology described below, it is assumed the battery has been sized in accordance IEEE Std 485-1997, using an aging factor 1.25. The test discharge includes all peak loads of the duty cycle that are above the normal performance test rate, while the performance test rate is adjusted so that no more than 80% of rated capacity is removed during the duty cycle time. The methodology also assumes that margin beyond the aging value is present.

METHODOLOGY

1) Determine the length of the duty cycle and multiply by 1.25. This is now the base time for the modified performance test.
2) From the manufacturer's literature, determine the discharge rate for the new base time.
3) Determine what portions of the duty cycle are above the rated current value determined in step 2).
4) Determine the capacity removed from the battery for each portion of the duty cycle that the current is above discharge current determined in step 3).
5) Determine the capacity the battery will deliver at the new discharge rate from step 2) for the time calculated in step 1).
6) Multiply the value obtained in step 5) by 0.80.
7) Subtract the value obtained in step 4) from the value obtained in step 6).
8) Divide the value obtained in step 7) by the remaining time of the Duty Cycle, after subtracting the time for the loads identified in step 3). This will be the new baseline current for the first 80% of the test time.
9) Superimpose the original duty cycle on top of the new minimum current value to obtain the MPT duty cycle for the first 80% of the test time. If there are any loads below the current determined in step 2), but above the new baseline current from step 8), repeat steps 3) through 9), including such loads in the calculations.

10) At the end of the 80% period the test discharge current returns to the value determined in step 2).
11) Record the battery terminal voltage just before each load change. After adjusting the load current to the final rate, follow the instructions of 7.4 c) through h). Note that if there is any interruption of the test before duty cycle duration has elapsed, the requirements of the service test will not have been met.
12) Determine the battery capacity in accordance with 7.3.1.2, using the total time taken to reach the minimum battery terminal voltage.

EXAMPLE

Period	Duration of each step of duty cycle	Current for each step of duty cycle
1	0–60 seconds	1000.0 amperes
2	1–30 minutes	725.0 amperes
3	30–60 minutes	454.0 amperes
4	60–180 minutes	350.0 amperes
5	180–239 minutes	70.44 amperes
6	239–240 minutes	29.44 amperes

1. Determine the length of the duty cycle and multiply by 1.25. This is now the base time for the modified performance test.

The designed battery duty cycle covers a period of 4 hours. Multiply this value by 1.25 to equal 5 hours.

2. From the manufacturer's literature, determine the discharge time for the new base rate.

The manufacturer's literature states that the 5 hour discharge rate for the battery is equal to 425 amperes.

3. Determine what portions of the duty cycle are above the current for the length of the new base time.

An examination of the duty cycle shows that the discharge currents for periods 1, 2, and 3 are above the 400A rating.

4. Determine the capacity removed from the battery for each of the duty cycle portions determined in step 3.

0–60 seconds
1000 amperes × [1 minute / 60 minutes in hour] = 16.7 Amperes per hour (Ah)

1–30 minute
725 amperes × [29 minutes/60 minutes] = 350.4 Ah

30–60 minute
454 amperes × [30 minutes/60 minutes] = 227.0 Ah

594.1 Ah

5. Determine the capacity the battery will deliver at the new discharge rate from step 2 for the time calculated in step 1.

425 amperes for 5 hours = 2125 Ah

6. Multiply the value obtained in step 5 by 0.80.

2125 AH × 0.80 = 1700 Ah

7. Subtract the value obtained in step 4 from the value obtained in step 6.

1700 Ah – 594.1 Ah = 1105.9 Ah

8. Divide the value obtained in step 7 by the remaining time of duty cycle after subtracting the time for the loads identified in step 3. This will be the new baseline current for the first 80% of the test. Total time for loads identified in step 3 = 1 + 29 + 30 = 60 minutes. The remaining time in the 4 hour duty cycle is 3 hours.

1105.9 AH × 3.0/H = 368.6 Amperes

9. Superimpose the original duty cycle on top of the new minimum current value to obtain the MPT duty cycle for the first 80% of the test.

Period	Duration of each step of duty cycle	Current for each step of duty cycle
1	0–60 seconds	1000.0 amperes
2	1–30 minutes	725.0 amperes
3	30–60 minutes	454.0 amperes
4	60–240 minutes	368.6 amperes

10. At the end of the 80% period the test discharge current returns to the value determined in step 2.

Period	Duration of each step of MPT	Current for each step of MPT
1	0–60 seconds	1000.0 amperes
2	1–30 minutes	725.0 amperes
3	30–60 minutes	454.0 amperes
4	60–240 minutes	368.6 amperes
5	240-end minutes	425.0 amperes

I.3 Type 3 modified performance test

The procedure for this test is to perform a standard service test (see 7.5), followed immediately by a discharge at the normal performance test rate. This test can take longer to perform than the type 1 or 2 MPT, but can be used for all applications including those that have peak loads near the end of the duty cycle.

METHODOLOGY

1) Determine the service test procedure and acceptance criteria in accordance with 6.3.
2) Determine the discharge rate normally used for the performance test. This is the uncorrected rate, without any temperature adjustment. Determine the rated ampere-hours for this rate.
3) Initiate the service test (first) portion of the test, using the test procedure from step 1) above.
4) At the end of the service test portion, adjust the discharge rate to that determined for the performance test from step 2) above.
5) Continue the last, performance test portion of the test in accordance with the normal performance test procedure.
6) At the conclusion of the test, calculate the battery capacity using the following equation.

$$\%\ \text{Capacity} = \frac{K \times \sum I_N \times T_N}{RtdAmp - hrs} \times 100$$

where:

K = temperature correction factor from Table 1 for initial temperature,
I_N = Discharge current in amperes for section N,
T_N = Duration of section N discharge in hours,
N = Section numbers for each portion of discharge test,
RtdAmp–hrs.= Rated Ampere-hours from step 2) above.

An example of this type of test is as follows:

A battery with a 2-hour rating of 1513 Ampere-hours uses a 2-hour discharge rate of 756.5 Amperes for a performance test. Assume the initial temperature for the test is 25 °C (77 °F). The battery duty cycle is given in sections 1 through 3 of the following table.

Section number	Load amps	Duration (in hours)	Section Ah	Cumulative Ah
1	1500	0.02	30	30
2	200	1.92	384	414
3	1200	0.07	84	498

Assuming the performance test duration is 50 minutes (.83 hours), the calculated battery capacity is as follows:

$$\%\ \text{Capacity} = \frac{1.00[1500 \times 0.02 + 200 \times 1.92 + 1200 \times 0.07 + 756.5 \times 0.83]}{1513} \times 100 = 103.9\%$$

Annex J

(informative)

Alternate inspection methods

Internal ohmic measurements [conductance, impedance, and resistance measurements] can be used in the field to evaluate the electrochemical characteristics of battery cells. The measurements can provide possible indication of battery cell problems and may identify those cells that have internal degradation.

The results obtained by the different types of technology or slight changes in instrumentation for a particular technology are not the same. The measurement data will differ with each style and model of instrument. The consistent use of the same type and model of instrument will provide the most consistent results. If internal ohmic measurements are taken with different types or model instruments on a given cell, the data must be carefully evaluated because of the above described difference in this measurement technology.

All internal ohmic readings should be taken in a consistent manner (e.g., at full charge and as close as possible to the same temperature [If readings cannot be taken at close to the same temperature, contact your test set manufacturer for correction factors]). Baseline measurements should be taken within 6 months of installation. The results of the internal ohmic measurement should be investigated when a significant change in cell measurements occurs over a period of time. Significant changes (e.g., over 100% for impedance and resistance measurements and 50% for conductance measurements) in the internal ohmic value of a cell are an indication of internal cell degradation. Changes less that these values may indicate possible problems, which could be confirmed by a discharge test.

The internal ohmic characteristics of a cell consists of a number of factors, including the physical connection resistances, the ionic conductivity of the electrolyte, and the activity of electrochemical processes occurring at the plate surfaces. With multi-cell units, there are additional contributions due to intercell connections.

After making initial measurements using the particular technique, the observed values should be recorded as baseline values. The type of test equipment used, the test points selected, cell/unit voltages, and electrolyte temperatures should be recorded for future reference.

Annex K

(informative)

Calculation of battery capacity

Capacity testing (acceptance, performance, and modified performance tests) is used to trend battery aging. The result of a capacity test is a calculation of the capacity of the battery. The calculated capacity is also used to determine if the battery requires replacement (see Clause 8).

K.1 Comparison of time- and rate-adjusted performance test methods

Performance testing is used to trend battery aging and to determine when to replace the battery (see Clause 8). The end-of-life point is determined by the aging factor used in the sizing calculation (see IEEE Std 485-1997). The recommended practice is to use a 1.25 aging factor and to replace the battery when the available capacity drops to 80% of rated.

The aging factor is applied to the base capacity required to satisfy the duty cycle. For a range of cells in which the capacity rating factors are constant, published ratings are proportional to the rated capacity. Thus, 80% of rated capacity also corresponds to 80% of the published rating for a given time. For example, if the published rating for a cell is 100 A for 240 minutes, the end-of-life capability will be 80 A for 240 minutes. This is the basis of the rate-adjusted performance test method.

As demonstrated in K.2, a calculation of battery capacity using the rate-adjusted method can be somewhat complex. While it is technically correct to use the rate-adjusted method for all test times, the recommended practice is to limit its use to tests with a nominal duration of 60 minutes or less. For longer test times, a simpler approach is to use the time-adjusted method. In this method, the end-of-life condition is defined using 100% of published current for 80% of the time. Thus, a cell rated at 100 A for 240 minutes would have an end-of-life capability of 100 A for 240 × 0.8 = 192 minutes. The calculation of capacity is a simple ratio of the test time to the published time (ignoring temperature adjustments). Because of its simplicity, this method is preferred for tests of long duration.

The time-adjusted method, however, does not take into account changes in battery efficiency with discharge time. Table K.1 shows the published current ratings for the XYZ33 cell type and gives the available capacity (in ampere hours and percent of rated capacity) for various discharge times, to an end voltage of 1.75V/cell.

Table K.1—Example values

	8h	6h	4h	3h	2h	90m	60m	30m	25m	15m	1m
Rated current (A)	290	368	496	613	800	944	1168	1536	1616	1840	2240
Available capacity (Ah)	2320	2208	1984	1839	1600	1416	1168	768	673	460	37
% of rated Ah	100	95	86	79	69	61	50	33	29	20	2

If the time-adjusted method is used for an 8-hour test, the end-of-life point corresponds to 6.4 hours (80% of 8 hours). The table shows that, in a 6.4-hour discharge, a new battery gives about 96% of its 8-hour capacity. This 4% reduction is due to a loss of battery efficiency at the shorter discharge time, and is expected to be approximately the same for a battery at the end of life. Thus, when an XYZ33 battery is discharged at the 8-hour rate of 290A, and gives 6.4 hours, three-quarters of the shortfall is due to battery degradation and one quarter is due to reduced efficiency. This results in a somewhat conservative end-of-life assessment.

For a 30-minute test, however, the end-of-life point by the time-adjusted method would be 24 minutes. The capacity availability at 24 minutes is only about 86% of the 30-minute capacity. Thus, an end-of-life assessment by the time-adjusted method would include only one-quarter battery degradation and three-quarters reduced efficiency. This would result in an excessively conservative decision regarding battery replacement.

By contrast, the rate-adjusted performance test method gives results that are exactly in accordance with the sizing parameters. It should be noted, however, that there is no conservatism in a replacement decision based on 80% of rating, so a timely replacement may be more critical. For a battery in which there is no planned or remaining design margin (see IEEE Std 485-1997), the user may wish to adopt a more conservative replacement strategy, such as replacement at 85% of rating.

There is a crossover point at which the time-adjusted method can no longer be considered valid. This corresponds to a lower time limit where the conservatism of this method becomes excessive. The value of this limit depends on the cell design and, to some extent, the users outlook. For a cell type designed for long duration telecommunications loads, the crossover point may be three hours or more. For a high-rate UPS cell, the crossover point may be less than 1 hour. For the XYZ33 cell type shown in Table K.1, the end of life for a 120-minute test by the time-adjusted method would correspond to about one-half degradation and one-half reduced efficiency. This would result in a reasonable level of conservatism for most applications. Consult the battery manufacturer for specific information.

K.2 Capacity calculation examples

Application of the formula for capacity calculation in 7.3.2 requires that a published performance rating be established for the actual test time, t_a. Where the time increments between published data points are small, it may be possible to use simple interpolation to calculate this rating. Otherwise, it is necessary to construct a graph of the published data. Figure K.1 shows a graphical representation of the data in Table K.1 for the XYZ33 cell type.

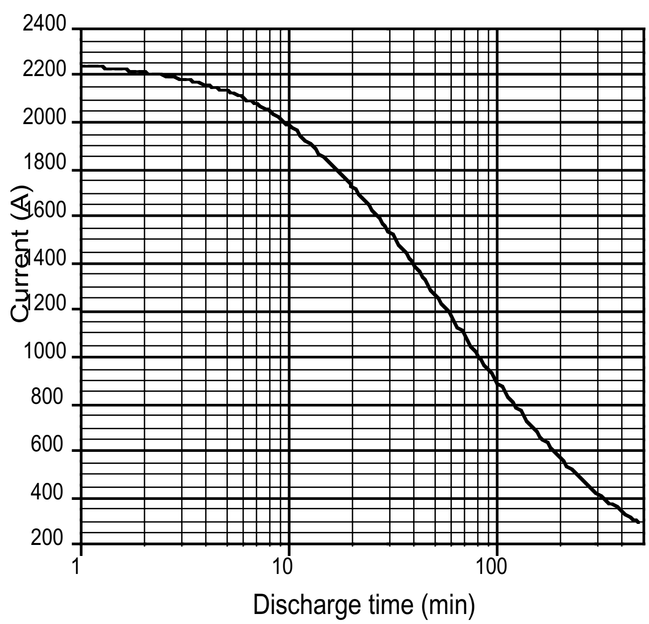


Figure K.1—Rated amperes verses discharge time

K.2.1 Example – 15-minute duty

An XYZ33 battery has been installed for a 15-minute duty. The original sizing included a 1.25 aging factor. The discharge rate for the performance test is therefore 80% of the published 15-minute rate of 1840A, or 1472A. (The test temperature is assumed to be 25°C, so there is no adjustment for temperature.) After several years of operation, the performance test duration is 18 minutes.

From Figure K.1, the rated current for 18 minutes is approximately 1760A. The calculated capacity is therefore:

$$\frac{1472}{1760} \times 100 = 83.6\%$$

In this example, it can be seen that the end-of-life condition corresponds to a test time of 15 minutes. Since the test rate is 80% of the published 15-minute rate, the calculated capacity will also be 80%.

K.2.2 Interpretation of data from tests carried out at full published rates

It is possible to apply the capacity calculation formula for the rate-adjusted method to other test results, where testing may have been carried out at the full published discharge rate. For example, if a test of an XYZ33 battery at the full 15-minute rate of 1840A yielded a 12-minute test time (for which the published current from Figure K.1 is approximately 1925A), the calculated capacity is

$$\frac{1840}{1925} \times 100 = 95.6\%$$

From the 80% curve, shown in Figure K.2, the XYZ33 is capable of providing approximately 1800A for 1 minute at the end of life. Therefore, a test of an 80% battery at the published 15-minute rate of 1840A will result in a discharge time of less than 1 minute. Although this may appear to indicate a catastrophic failure, it is actually a function of the battery’s inherent performance capability, and its efficiency for short, high-rate discharges.

This calculation demonstrates the large differences between the time-adjusted and rate-adjusted methods for short duration tests. The time-adjusted method gives a result of 80% capacity (12 minutes as a percentage of 15 minutes), but three quarters of this capacity shortfall is due to the lower efficiency of the battery at the 12-minute rate (see K.1). Depending on the design of the cell being tested, the results of a time-adjusted test may be extremely misleading, as demonstrated in Figure K.2. This graph shows the same published rating curve for the XYZ33 cell type, and also shows the end-of-life condition, corresponding to 80% of the published ratings assuming a 1.25 aging margin.

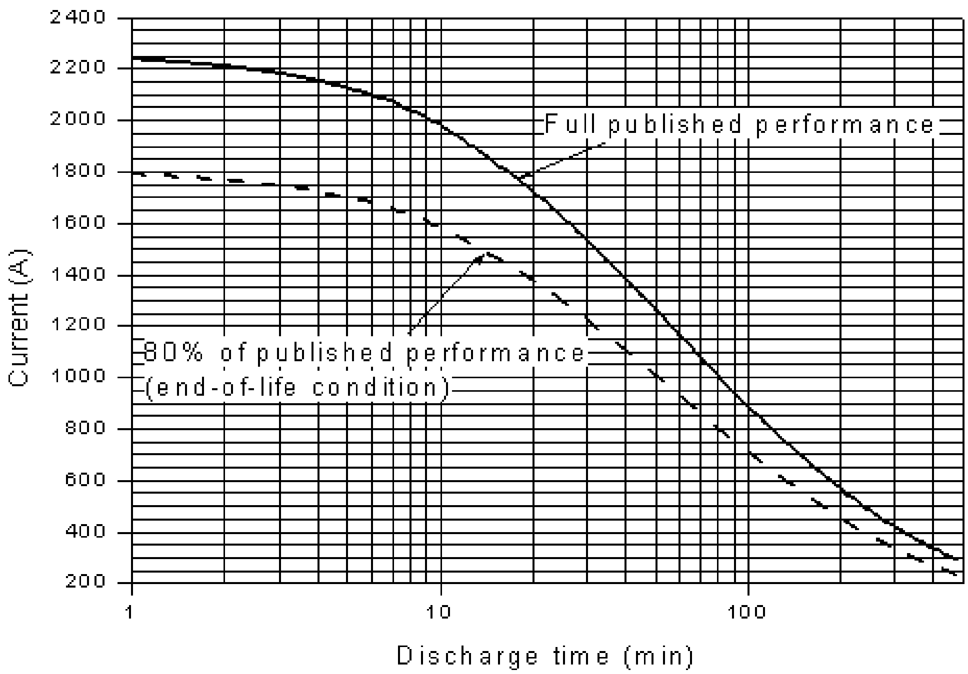


Figure K.2— Comparison of rate verses time adjusted end of life prediction

K.2.3 Application of rate-adjusted method for other end-of-life conditions

The preceding examples have assumed that a 1.25 aging factor was used in the sizing calculation (see IEEE Std 485-1997), corresponding to an end-of-life condition at 80% of rating. The rate-adjusted method can be equally applied for other end-of-life conditions.

Example 1. If an aging factor of 1.11 was used for sizing a battery for a 15-minute duty, the end-of-life condition is 90% of the published 15-minute rate. The battery is tested at 90% of the published 15-minute rate, and is judged to be at the end of life when is fails to supply this rate for the full 15 minutes.

Example 2. If no compensation for aging was included in the sizing calculation, the aging factor is 1.00, the end-of-life condition is 100% of rating, and the derating factor for the test rate is 1.00. The test discharge rate is therefore equal to the published rate, and the battery will be judged to be at the end of life when it can no longer provide this rate for the full published time.

While these applications of the rate-adjusted method maintain consistency between battery sizing and testing, it should be noted that manufacturers' warranties are generally based on 80% of published performance, and such batteries would not be eligible for warranty adjustment.

Annex L

(informative)

Temperature correction factors

Table L.1—Recommended time correction factors (K_T) for temperatures other than 25 °C (77 °F)

Initial temperature (°C)	Initial temperature (°F)	Temperature correction factor K_T	Initial temperature (°C)	Initial temperature (°F)	Temperature correction factor K_T
4.4	40	0.670	26.1	79	1.007
7.2	45	0.735	26.7	80	1.011
10.0	50	0.790	27.2	81	1.017
12.8	55	0.840	27.8	82	1.023
15.6	60	0.882	28.3	83	1.030
18.3	65	0.920	28.9	84	1.035
18.9	66	0.927	29.4	85	1.040
19.4	67	0.935	30.0	86	1.045
20.0	68	0.942	30.6	87	1.050
20.6	69	0.948	31.1	88	1.055
21.1	70	0.955	31.6	89	1.060
21.7	71	0.960	32.2	90	1.065
22.2	72	0.970	35.0	95	1.090
22.8	73	0.975	37.8	100	1.112
23.4	74	0.980	40.6	105	1.140
23.9	75	0.985	43.3	110	1.162
24.5	76	0.990	46.1	115	1.187
25.0	77	1.000	48.9	120	1.210
25.6	78	1.002			

NOTE—This table is based on nominal 1.215 specific gravity cells. For cells with other specific gravities, refer to the manufacturer. The manufacturer's recommend that battery testing be performed between 18.3 °C (65 °F) and 32.2 °C (90 °F). These values are average for all time rates between 1 hour and 8 hours.

Temperature rate correction factors

Table L.2—Recommended current rate correction factors (K_C) for temperatures other than 25 °C (77 °F)

Initial temperature (°C)	Initial temperature (°F)	Temperature correction factor K_C	Initial temperature (°C)	Initial temperature (°F)	Temperature correction factor K_C
4.4	40	1.300	26.1	79	0.987
7.2	45	1.250	26.7	80	0.980
10.0	50	1.190	27.2	81	0.976
12.8	55	1.150	27.8	82	0.972
15.6	60	1.110	28.3	83	0.968
18.3	65	1.080	28.9	84	0.964
18.9	66	1.072	29.4	85	0.960
19.4	67	1.064	30.0	86	0.956
20.0	68	1.056	30.6	87	0.952
20.6	69	1.048	31.1	88	0.948
21.1	70	1.040	31.6	89	0.944
21.7	71	1.034	32.2	90	0.940
22.2	72	1.029	35.0	95	0.930
22.8	73	1.023	37.8	100	0.910
23.4	74	1.017	40.6	105	0.890
23.9	75	1.011	43.3	110	0.880
24.5	76	1.006	46.1	115	0.870
25.0	77	1.000	48.9	120	0.860
25.6	78	0.994			

NOTE—This table is based on nominal 1.215 specific gravity cells. For cells with other specific gravities, refer to the manufacturer. The manufacturer's recommend that battery testing be performed between 18.3 °C (65 °F) and 32.2 °C (90 °F).

Annex M

(informative)

Bibliography

[B1] IEEE 100™, *The Authoritative Dictionary of IEEE Standards Terms,* Seventh Edition.[3]

[B2] IEEE Std 308™-1991, IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations.

[B3] IEEE Std 323™-1983 (Reaff 1996), IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations.

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[B6] IEEE Std 946™-1992, IEEE 946-1992 IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Stations.

[B7] IEEE Std 1375™-1998, IEEE Guide for the Protection of Stationary Battery Systems.

[3]The IEEE standards or products referred to in this annex are trademarks owned by the Institute of Electrical and Electronics Engineers, Incorporated.

[4]IEEE Std 494-1974 has been withdrawn; however, it is still applicable to this document. Copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).

